ELECTROSTATIC PRECIPITATORS AND COLLECTION OF FLY-ASH FROM LOW SULPHUR COALS

STANDARDS DEVELOPMENT BRANCH OMOE
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Report No. ARB-TDA-12-75

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Ontario

Ministry of the Environment

The Honourable George A. Kerr, Q.C., Minister

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AIR RESOURCES BRANCH

Technology Development & Appraisal Section

Report No. ARB-TDA-12-75

Electrostatic Precipitators

and

Collection of fly-ash from Low Sulphur Coals

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1.0 SUMMARY

A brief description of the principles of separation of particulate matter from gas streams by electrostatic precipitation is given. This is followed by a review of the design criteria for such precipitators and the importance of such parameters as high resistivity of ash from low-sulphur coals, a fuel which may become increasingly common because of strict SO_2 control regulations. Methods of overcoming fly-ash collection problems for such coals e.g., gas conditioning, installation of precipitator ahead of the air-preheater ("hot" precipitator) etc., are described. Operating data and experience at some power stations using low-sulphur coals are detailed. A brief section on costs is also included. As more detailed operating experience including cost data becomes available for hot precipitators, updating of this review will be required.

2.0. RECOMMENDATIONS

An updated report on the operating experience of hot precipitators including reliability, economic attractiveness, and any special problems should be prepared by the Technology Development and Appraisal Section by the end of 1976. This task should require about 4 man-months.

3.0 INTRODUCTION:[1]

Experiments on the separation of suspended particulate matter from gases by use of electrostatic forces were done as early as in the eighteenth century. Following much more work in the nineteenth century; the successful development of industrial electrostatic precipitators is generally attributed to Cottrell during the early years of this century. Starting with the control of the non-ferrous smelting industry, the technology spread fast to cover almost all heavy industry, particularly to the collection of fly-ash from power generating boilers; a field which at present is estimated to use 75% of all installed precipitator capacity in terms of volume of gas treated. Other main users of the devices apart from the non-ferrous metals industry are cement, paper mill and chemical industries. As air pollution control regulations tighten more and more use is being made of electrostatic precipitators in various modifications, notably high-temperature use to avoid high-resistivity problems, odour control, wet precipitators in aluminum reduction processes, etc. A cut-away view of one type of electrostatic precipitator is shown in Figure 1.

Current technology can achieve efficiencies of over 99% in most applications, however complex problems are encountered because of the corrosive nature of gases, temperature limitations, small size and resistivity of the particles to be collected. In an effort to control SO_2 emission, low sulphur coals may come into wider use. However, the fly-ash from these coals shows very high resistivity (order of 2 x 10" ohm-cm) at normal collecting temperatures, which results in reduced collection efficiencies. Methods such as gas conditioning, control of alkali content and high-temperature collection of fly-ash are being developed for overcoming these problems.

While the use of electrostatic precipitators has grown very rapidly, the design and selection of the unit for a particular service remains very subjective and heavily influenced by the experience of the

vendor, and as such it is possible that competing vendors may submit bids specifying equipment of various sizes for the same service. To resolve this, various attempts are being made to quantify aspects of design. A recent APCA report (Ref. 35) recommends a long list of information required for the selection and application of precipitators (appendix), but does not indicate how the information is applied.

4.0 BASIC THEORY[(1)(2)(3)]

In an electrostatic precipitation process, the following sequence of events takes place:

(a) The dust contained in the gas to be cleaned is charged by means of a high voltage, direct current corona.

(b) The gas then passes through an electric field, where electrical forces cause the dust particles to move (migrate) towards a collection surface (electrode).

(c) the collected dust on the electrode is removed, by rapping systems. Various physical configurations are used to effect these three components of the precipitation process.

(a) Corona generation

If the high voltage is applied to a set of two electrodes, one of which is a thin wire and the other a plate, a high density electric field results near the wire, which decreases inversely with the distance (radius) from the wire surface. The electrons (natural or otherwise introduced) in this electric field are accelerated to high velocities and when a gas is present, these electrons, on impact with the gas molecules, knock off more electrons which in turn also take part in this ionization process, leaving positively charged ions. The process persists until the distance from the thin wire is such that the electrical field cannot provide enough energy to the electrons. This region of ionization is the corona glow

discharge, and the corona can be positive or negative depending on the polarity of the discharge electrode, and is of the same polarity.

Since in most industrial uses, a negative corona is used, the following comments will be restricted to this type.

(b) Charging and migration of dust particles

The dust particles in the gas stream can be charged by the accretion of the ions by two processes -- field-dependent and diffusion.

In the field-dependent type, the amount of charge a particle can accept from the ions in the electric field is proportional to the square of the particle diameter. In the diffusion type (normally on small 0.2 u particles), the charging is related to the thermal motion and gradients in the system.

The charged particles move toward the oppositely charged collecting electrode with a velocity known as the "migration" velocity. This terminal velocity is reached when the electrical force on the particle is equalled by the viscous drag force of the gas.

The amount of charge a particle carries and the migration velocity are both related to particle size, so that for any real dust the migration velocity used in design calculations is an "average" velocity based on the experience of suppliers and other investigations. Although some efforts have been made to determine migration velocities for narrow particle size ranges of fly ash dusts, the variations in the properties of the fly ash, produced under different conditions, make this approach of limited value. The migration velocities used in design work continue to be empirically obtained values.

The migration velocity is important in determining the collection efficiency of the precipitator which is defined by the Deutsch-Andersen equation:

$$N = 100 \left(1 - \exp. \frac{-WA}{V} \right)$$

where: N = collection efficiency %

W = migration velocity.

A = area of collecting electrode

V = gas flow volume

Many other modified equations have been produced for calculation of migration velocity.

(c) Collection and removal of dust

After the migration and retention of the dust to the collecting electrode is achieved, the material must be dislodged from the electrode, and in the case of dust (as opposed to droplets) effective rapping of the electrodes is essential. The effectiveness of rapping includes not only the ability to dislodge the accumulation of dust into a hopper but also to minimize the re-entrainment in the gas stream. Successful rapping of the electrode, which imparts an acceleration to remove the dust, has to overcome forces of cohesion and adhesion apart from mechanical and electrical forces.

The dust falls into a hopper or similar storage from where it can be removed in various ways.

5.0 DESIGN

The design of an electrostatic precipitator to provide a specified level of efficiency at specified conditions of service, involves the determination of the physical size, the electrodes, rapping system, electrical system and the supports.

5.1 SIZE[1][2]

The size of the unit is derived from the calculation of the Deutsch-Anderson equation, bearing in mind that the equation applies properly only to particles of a uniform size. Corrections have to be made to provide for effects of channelling and sectionalization of gas flow, re-entrainment of dust and the gas. For this the vendor utilizes the information available from past experience. The Deutsch-Anderson equation involves the migration velocity which is greatly influenced by the temperature of the gas and the resistivity of the dust (Fig. 2).[17] Because of the presence of many variables which play a role in determining the migration velocity; the manufacturer of the equipment can make use of the past performance data in his possession and produce theoretical models for calculation of sizes. Use of Regression Analysis is one of the methods for producing such specifications for a new unit.

Correlations have also been produced to show that the collecting area required to produce a given efficiency is dependant on the percentage of sulphur in the coal being burnt (Fig. 3).[2][9][20] However, because of temperature variations and many other different constituents of coals, these graphs can't be generally extrapolated.

The sizing of the precipitator can also be achieved in some instances from pilot-plant tests. However, due to scale-up problems with current densities, gas-flow patterns, efficiencies, etc. results have to be interpreted carefully.

An important aspect of the design is the determination of gas flow and velocity. These velocities are specified based on the properties of the dust, e.g., if the dust is light and fluffy and hence easily re-entrained, the velocities are kept low. Uneven gas flow through the unit can cause unequal treatment time for the dust passing, and hence seriously affects the efficiency of the collection.

5.2 Electrodes[1][2]

The precipitators are generally distinguished by the type of electrodes used.

In tubular precipitators, the collection electrodes are placed at the axis of the cylinder. Gas to be cleaned passes through the outer cylinder.

In the common form of dry precipitators, the collection electrodes are in the form of parallel plates placed about 6-12 inches apart with the discharge electrodes located between these plates. The plates can, depending on the service, be as high as 40' or more. As the primary function of the discharge electrodes is to provide adequate electrical field, electrodes are installed in various shapes - wires or fabricated structure. The wires can be held down by weights (Fig. 4) or can be supported by a mast or similar rigid structure. Mechanical fatigue, corrosion and temperature-caused failures are the problems that have also to be looked into when specifying the physical shape of the electrodes. Figs. 5 & 6 show[2][20] some of the types and shapes of discharge and collecting electrodes respectively. Figs. 7 & 8 show[20] support structures for some of the electrodes. The design includes the determination of the number of power sets for providing the supply. Sectionalizing the precipitator and using a large number of power sets offers many advantages by way of higher voltages, better control etc; however, because of cost limitations, large sections using smaller numbers of power supply sets are frequently used.

The strength of the electrical field supplied is limited by the properties of the dust/gas. The maximum field strength is reached when an electrical breakdown of the gas is indicated by sparking between the two electrodes, which reduces the current considerably. Some correlations have been empirically derived for fly-ash and recovery boiler precipitators showing the nature of migration velocity and the power density variations.

5.3 Rappers

Once the dust has formed, it agglomerates on the collecting electrode and it can be dislodged by mechanically, electromagnetically or pneumatically actuated rapping systems. Electrical vibrators can also be used. Common type of rappers employ weights lifted by various methods and falling on anvils connected to the collecting plates. Fig. 9[20] shows one type of mechanical rapper.

The rapping intensity and the energy imparted by the rappers are limited by the structural soundness and support system strength. The intensity also has to be matched to the resistivity, the density of the dust, and the amount of dust re-entrainment after rapping. The different manufacturers have many different designs for the rapping and the support mechanisms.

6.0 ELECTROSTATIC PRECIPITATORS & LOW-SULPHUR COALS

As has been noted; about 3/4ths of all precipitators in use control the fly-ash emissions from fossil-fired power plants. This industry is going to look more and more at coal as a fairly large source of energy in the coming years. A large part of the reserves of coal, contain very small amounts of sulphur (1% or less). Even as early as 1910-1920 it was observed that the resistivity of the dust particles is indirectly proportional to the SO_3 content of the flue gas, i.e., good collection efficiencies were obtained when considerable SO_3 concentration was present. Since then various experimental research programs have concluded that absorption of compounds such as NH_3, SO_3, H_2O etc. on the ash particles have effects on the conductivity (resistivity). It has recently been noted that presence of sodium compounds also influences resistivity (17) of the ash, the higher the sodium content the lower the resistivity. This can be either naturally occurring sodium or externally supplied.

Normally with 2-3% sulphur coals, precipitators are installed after the air-preheaters so that the flue-gas temperature is in the order of 250^{o}-350^{o}F. When low sulphur coals are burnt, it is found that because of high resistivity at these temperatures, efficiencies of these precipitators are very low. It has also been found that if the precipitators could be installed before the air preheaters i.e., at about 500-700^{o}F flue-gas temperatures (so-called "hot" precipitators) because of the resistivity/temperature relationship much better efficiencies could be obtained. (13) → (18) (12) Fig. 10 shows resisitivity/temperature plots for a number of U.S. coals.

The various problems associated with this kind of installation and the operating histories of some plants are discussed in the following pages.

6.1 Resistivity [2][17][18]

About 30 million tons of fly-ash are produced yearly from the combustion of fossil-fuels in the U.S. alone. The conductivity (or resistivity) of these particles in an electrical field is one of the critical parameters in the design of electrostatic precipitators for the collection of this fly-ash.[17] Fig. 11 shows the temperature/resistivity relationships with the sulphur content for some coals. When a layer of high resistivity particles start to build up on the collecting electrode, a point is reached where the corona ions begin to be impeded by the resistance of the layer. This causes the voltage to increase across the layer and to decrease across the gas, causing a loss of corona current. As the layer keeps building up, the voltage across the layer progressively increases and causes an electrical breakdown of the layer, which causes the layer to start forming small holes or craters through which discharges (commonly called Back Corona) occur[18] (Fig. 12). Normally the resistivity at which this phenomenon arises is in the order of 10^{10} - 10^{11} ohm.cm. for the common fly-ash. These disruptions of normal corona patterns cause serious loss of **collection efficiency** for the precipitator. There appear to be two conduction mechanisms which determine the electrical resistivity of a bulk layer of particles. Electric charges can be carried in the surface moisture and chemical films absorbed in these particles, this leads to surface conduction[2][17] and this mechanism is dominant below about 300-350°F. Fig. 13 shows the effect of humidity on this type of conduction. This conduction appears to be electrolytic or ionic in nature and it has been found that in some cases a chemical conditioning agent can further enhance the absorption of moisture and hence the conductivity of the particle. Recent analyses of various kinds of fly-ash have indicated the possibility of alkali metal ions as being responsible to a degree for this <u>surface conduction</u>. It appears that the higher the concentration of alkali metal (specially sodium) ions,[11][14][24] the higher the conductivity.

The other mechanism of conduction called Volume conductivity depends on the motions of electrical charges through the interior of the particle and hence depends on the composition and temperature of the particles. This mechanism comes into play above 300^{o}F; and is believed to be ionic or electronic in nature. The sodium ions once again are believed to be the charge carriers according to recent research. Recent research work indicates that sodium ions can also be a major factor in the transport of charges through the particles.

7.0 METHODS OF CONTROL OF FLY-ASH FROM LOW-SULPHUR COALS

In many installations it has been found that, despite the high resistivity, good efficiencies can be obtained with precipitator installations at normal temperatures if the equipment has been sized properly. However, in many instances due to a very low Na_2O content of the fly ash or economic reasons, precipitator installations are specified at the higher temperatures before the air-preheaters.

The other commonly used method if flue-gas conditioning with various chemicals or water.

In some cases it may be possible to blend low-sulphur coals with high-sulphur coals (as long as SO_2 emissions do not exceed regulations). It should also be noted that where high-sulphur coals are burnt, and SO_2 emissions need to be controlled, blending of high and low sulphur coals can once again offer a solution, as long as the precipitator can handle the extra ash (from the low-sulphur coal) and as long as the resistivity of the ash from the blend is still within the limits of good precipitation.

The following sections give some details about these methods by way of operating experiences from a few plants and data supplied by some manufacturers of such equipment.

7.1 Hot and Cold Precipitators

Both hot and cold precipitators have been installed at power stations burning low-sulphur fuels. There seems to be a lot of controversy over the superiority of one type over the other. Various articles have appeared in the literature listing the advantages of each type.[13][14] Regression analyses are being carried out on collected data for use in efficiency prediction and design work.

Because of the high resistivity of the fly-ash, fairly large collecting areas are sometimes required for installations intended to remove the fly-ash at normal temperatures of 250^{o}-350^{o}F; and this can be translated into high capital costs. On the other hand, hot precipitators can also mean large sizes due to the higher gas flows. There can also be extensive insulation and ducting costs. It is thought that the maintenance and general operating costs for hot precipitators can also be higher. Special attention has to be given to the selection of materials of construction for some sections of the hot precipitator and to the specifications of some stress-bearing members because of the higher temperatures involved.

It is argued that for high resistivity, low sulphur type fuel, it is better to have the "hot" type precipitators (i.e., installation before preheaters), because of four main reasons:[8][15][17][29]

1) the precipitator can be designed for operation without too much back-corona
2) it appears that at higher temperatures, resistivity variations occurring in the ash from different coals cover a smaller range than those at a lower temperature, hence the precipitator design can be such as to accomodate varying types of fuel supply.
3) the adhesive forces between the dust and the collecting

electrode are smaller at a higher temperature and hence the precipitator can be designed for less intense rapping, resulting in some cases in less maintenance, fewer fatigue failures, less re-entrainment etc.

4) Fig. 14[15] shows that at higher temperatures the corona current is enhanced resulting in increased power densities and hence more effective migration velocities.

It is probably best to do intensive testing on the fuel and the fly ash in order to determine the optimum design of the equipment in each individual case. No clear-cut advantages are apparent in all cases for either type, at this time.

7.1.1 Navajo Generating Station (27)

A "hot" precipitator was selected for the 750 MW unit #1 of the Navajo Station. The unit uses 8,000 tons/day of Black Mesa Coal. The analyses of the coal and the fly-ash are as follows:

Coal Analysis	Range wt.%	Fly-ash Analysis	Range wt.%
Moisture	9.73-16.0	Phos pentoxide, P_2O_5	0.08-0.57
Carbon	54.87-65.42	Silica, SiO_2	47.62-58.91
Hydrogen	3.91-4.62	Ferric oxide, Fe_2O_3	4.41-9.74
Oxygen	10.85-12.95	Alumina, Al_2O_3	16.72-24.87
Nitrogen	0.90-1.07	Titania, TiO_2	0.86-1.34
Sulfur	0.36-1.26	Lime, CaO	4.94-12.06
Ash	5.84-12.18	Magnesia, MgO	1.19-2.61
Chlorine	0.01-0.02	Sulfur trioxide, SO_3	2.16-10.8
		Potassium oxide, K_2O_3	0.39-1.19
		Sodium oxide, Na_2O	0.53-2.47

The flue-gas enters the precipitator at about 650°F before passing through the air-preheater. The preheater is 16-chambered and allows 1 chamber to be isolated for repairs at any time. Quite often ash-handling and removal processes are causes for precipitator outages. Care has been taken to insure that both front and rear fields of the precipitator have full capacity ash-removal systems. The migration velocity is designed as 0.29 ft./sec. with the plate-area/volume ratio of over 300 ft.^{2}/1000 cfm. The minimum required efficiency is 99.5% and the cost is over $100 million.

7.1.2 S.F. Precipitators (Flakt) (28)

A) Australia

S. F. "cold" precipitators were selected by the Electricity Commission of New South Wales (E.C.N.S.W.) for some of their low-sulphur coal-fired boilers. The analyses are as follows:

Power Station Colliery	Vales Point Newvale	Liddell Ravensworth	Wallerawang Newcorn
Coal Analysis			
Cal. Value Btu/lb	11,950	9,130	11,040
Volatile Matter	30.6	23.4	29.1
Fixed Carbon	50.7	43.0	45.9
Moisture	3.1	4.0	7.0
Ash	15.6	30.0	17.9
Sulphur	0.36	0.36	0.58
Ash Analysis			
SiO_2	55.6	57.8	63.1
Al_2O_3	29.6	28.9	26.8
Fe_2O_3	4.53	4.71	0.59
CaO	2.27	1.76	0.51
MgO	1.35	1.70	0.30
Na_2O	0.65	0.50	0.12
K_2O	2.98	1.27	2.52
SO_3	1.00	1.35	0.30
TiO_2	1.41	1.10	0.88

Vales Point (28)

Flakt received the order for the precipitators for boiler no. 4 in 1960. The plant has three three-field precipitators designed for a total efficiency of 99% on a gas quantity of 753,000 cfm. and an inlet dust concentration between 4-14 grains/normal cu. ft. dry basis. The station burns mainly Great Northern coal. Initially all three casings were equipped with solid type discharge electrodes. One casing was subsequently rebuilt to spiral electrodes and the efficiency was measured to be 99.7% on an inlet dust load of 9 gr./NCFD. Subsequent tests have been done from time to time on the installation and these have confirmed that this high efficiency of 99.7% is maintained.

Fläkt has recently received the order for the precipitators for the two new 660 MW boilers, which will be built at this power station. The gas quantity to be cleaned per boiler is 1,940,000 cfm. at 290^{o}F and the precipitators are guaranteed to give efficiency of 99.47% on an inlet dust loading of 5-14 gr./NCFD.

Liddell (28)

The Liddell power station has now been completed with four 500 MW units equipped with Fläkt precipitators. This power station burns coal basically from the so-called Bayswater seam.

This coal had previously not been mined and preliminary investigations indicated that the dust would be difficult to collect in electrostatic precipitators. E.C.N.S.W. therefore decided to perform tests with a Fläkt pilot plant at the Pyrmont Power Station. 5,000 tons of the new coal was mined and burnt in an existing boiler plant and a research note on the tests was issued and sent to all bidders on electrostatic precipitators as part of the specification.

Fläkt received the order with the arrangement that the gases from the two different air heaters should be cleaned separately in a total of five three-field precipitators per boiler. The total gas quantity of 4.9 million lbs/hr and the guaranteed efficiency 98.5% on an inlet dust loading of 4-14 gr./NCFD.

Tests were performed by E.C.N.S.W. in May, 1973 on the precipitators after boiler No. 2. A total of five tests were performed and the mean efficiency was found to be 98.82. In May and June, 1974, tests after boilers 1, 3 and 4 gave a mean efficiency which was slightly above 98.82.

Wallerawang (27)

The Wallerawang power station is presently being extended with a 500 MW boiler equipped with four five-field Fläkt precipitators. When planning the new 500 MW set at the station E.C.N.S.W. again decided to perform pilot plant testing with a Flakt pilot plant. Fläkt received the order for four five-field precipitators, which are now being erected. Because of the high resistivity of the dust, they have a larger specific collecting area than any other installation in the New South Wales and at the time of ordering, it was possibly the largest specific collecting area of any precipitator in the world. The plant is designed for a collecting efficiency of 98.5% on a gas quantity of 1,340,000 cfm at a temperature of 240^{o}F and an inlet dust concentration of 4-12 gr/NCFD. The plant is scheduled to go into operation in 1975.

B) U.S.A. (28)

Jim Bridger (28)

Pacific Power & Light Co. and Bechtel Power Corporation in San Fransisco decided to adopt the pilot-plant procedure when buying precipitators for the Jim Bridger power station, which is now being built in Wyoming for Pacific Power & Light Co. and Idaho Power Co.

Fläkt and their U.S. licensee for precipitators were chosen to perform such tests and subsequently received the order for the full scale plant.

Each of the four 500 MW sets at the Jim Bridger station will have a Flakt precipitator installation comprising six gas paths, each with five fields, but with space for a sixth field. Each precipitator plant is designed for an efficiency of 99.33% on a gas quantity of 1,770,000 cfm at a temperature of 250^{o}F and an inlet dust concentration of 5.4 gr/SCF. A typical composition of the coal during the tests is shown below:

Coal Analysis	Wt.%	Coal Ash Analysis	
		SiO_2	63.0
Cal. Value Btu/lb	11,650	Al_2O_3	15.7
Volatile Matter	29.9	Fe_2O_3	5.14
Fixed Carbon	40.6	CaO	7.3
Moisture	19.3	MgO	1.45
Ash	10.2	Na_2O	0.77
Sulphur	0.66	K_2O	0.56
		SO_3	5.07
		TiO_2	0.9

C) Canada [24][28]

i) Calgary Power [24][28]

The Sundance station of this power company has 2 X 300 MW units in operation and 3 X 375 MW units under construction. The analyses of the sub-bituminous coal and the fly-ash are as follows:[24]

Coal Analysis	Range, wt.%	Fly-ash Analysis	Wt.%
Moisture	19.01 - 20.89	SiO_2	50.38
Ash	13.80 - 17.88	Al_2O_3	26.11
Carbon	46.47 - 50.22	CaO	13.07
Hydrogen	4.66 - 5.12	Fe_2O_3	4.64
Nitrogen	0.45 - 0.63	MgO	0.97
Sulphur	0.15 - 0.22	K_2O	1.00
Oxygen	9.79 - 10.64	TiO_2	0.91
		Na_2O	2.26
		SO_3	0.41
		P_2O_5	0.23
		Li_2O	0.01

When the company decided to install e.s.p.'s on the 2 units it chose to first do its field tests, and interpret the data, so as to incorporate these into the specifications for the equipment. The company engaged the services of Dr. H. White, the well-known expert on the precipitation, to this end. A pilot-plant for treating 2500 cfm from #1 unit was installed. As resistivity measurement is one of the most important parameters in this work, an instrument for this measurement "in situ" was developed. Resistivity values of the order of 4-5 x 10^{10} ohm-cm. were recorded at temperatures of about 350^{o}F. It was also found that the ash could be readily precipitated. The S.F. "cold" precipitators selected for these units, based on the pilot-tests have design migration vel. of 0.27 ft./sec; gas vel. of 5.0 ft./sec. and 325 ft.^{2} collection surface/ 1000 cfm. The unit has 3 fields. Recent tests showed collection efficiencies of 99.7%.

The order for installation of precipitators on the 3 new units being constructed was also received by S.F. recently.

ii) Alberta Power [28]

Pilot-plant tests were done by this company prior to installing e.s.p.'s at the Battle River Station's existing (2 x 30 MW, and 1 x 150) and new (1 x 150 MW) units. The analysis were as follows:[28]

Coal Analysis	Wt.%	Coal Ash Analysis	Wt.%
Cal. Value Btu/lb	7,250	SiO_2	52.1
Volatile Matter	25.3	Al_2O_3	24.9
Fixed Carbon	32.2	Fe_2O_3	2.5
Moisture	28.5	CaO	6.1
Ash	14.0	MgO	0.9
Sulphur	0.4	Na_2O	2.43
		K_2O	1.24
		SO_3	-
		TiO_2	0.6

The total gas quantities are about 1.8×10^6 cfm with inlet dust concentrations of 0.9 gr./NCFD. The design efficiencies were 99.35% and it is understood that these were exceeded during actual operations.

At the Milner station (140 MW) of this power company, the low-sulphur coal has over 30% ash content and the fly-ash has about 0.6% Na_2O. It has been found that the ash is very difficult to precipitate and alternatives such as gas conditioning with sodium salts, SO_3, etc., and "hot" precipitators have been considered. No decision is know to have been made yet.

Company	Nominal Station MW Rating (MW)	Coal Analysis % S	Coal Analysis %Ash	Volume A.C.F.M.	Temperature °F	Outlet Loading grains/a.c.f.	Efficiency %	Remarks
A	100	1.9-2.7	8-11	433,200	612	0.0018	99.88	Each Precip. 2-chamber, 5-field, vel.6.1ft/sec.
	100	"	"	433,700	617	0.0036	99.74	
	200	1.9-2.7	8-11	403,600	598	0.0006	99.06	Each is 4-chamber 5-field 5.8ft./sec.
	200	"	"	492,000	603	0.0004	99.73	
	200	1.9-2.8	6-11.2	446,000	614	0.0003	99.82	Each is 4-chamber 5-field 5.8ft./sec.
	200	"	"	381,000/469,000	584/629	0.0064	99.18/99.32	
B	52	0.87	9.3	368,400	815	0.0036	99.51	2-chamber 4-field 5 ft./sec. vel.
C	175	0.8	17.4	944,300	596	0.015	99.39	Each unit 2-chamber 5-field 5 ft./sec. vel.
	185	"	"	860,000	600	0.0018	99.94	

7.1.3 A LISTING OF SOME HIGH-TEMPERATURE ELECTROSTATIC PRECIPITATORS[26]
installed by Western Precipitation Company

(...CONT'D)

Company	Nominal Station MW	Coal Analysis % S	%Ash	Volume A.C.F.M.	Temperature °F	Outlet Loading grains/a.c.f.	Efficiency %	Remarks
D	150	0.7-1.1	10	428,400	667	0.0035	99.75	2-chamber 4-field, 5 ft./sec
	150	"	"	676,500	637	0.0022	99.72	2-chamber 4-field 4.9 ft./se
E	Steam Plant	0.8	15.0	120,400	506	0.019	99.24	1-chamber 4-field 3.9 ft./se
		"	"	114,900	490	0.019	99.3	
F	Steam Plant	0.69	7.08	115,300	575	0.018	98.4	1-chamber 2-field 4.7 ft./se
		0.7	"	99,400	595	0.022	99.1	

7.1.3 continued

7.1.4 A LIST OF SOME HIGH-TEMPERATURE RESEARCH-COTTRELL PRECIPITATOR INSTALLATION (29)

Company No.	Gas Vol. ACFM	Gas Temp.	Design Perf. %	Tested Perf.%	Startup Date	% Sulphur In Coal
1	4,300,000	700	99+	99.7	10/67	0.9
2	540,000(ea.)	690	99	99.3	11/70	1.0
3	402,000(ea.)	700	99	99.1	10/71	1.0
4	1,350,000 (ea.)	650	99.2	Not Tested	10/72	0.75
5	400,000 (ea.)	688	99	99.3	2/73	0.75
6	400,000 (ea.)	675	99.5	99.9	11/72	0.9
7	1,250,000	650	99.3	99.6	10/72	0.7
8	691,300	680	99	Not Tested	12/72	1.2
9	400,000	620	97	99.3	3/73	0.9
10	248,500	802	99.0	99.6	3/73	0.8
11	1,425,000	675	98.5	Not Tested	4/73	0.5
12	669,000	725	99.5	"	5/73	0.7
13	2,514,000	828	99.59	"	8/73	0.3
14	2,770,000	810	99.5	"	6/75	0.5
15	974,000	550	99.5	"	11/73(11)	1.0
16	259,000	740	99.8	Not Tested	11/73	1.2
17	1,250,000	650	99.3	"	12/73	0.5
18	2,643,000	750	99.5	"	6/75	0.3
19	860,000	660	99.5	"	1/1/75	0.625
20	1,250,000	650	99.3	"	12/74	0.7
21	3,025,000/2	750	99.6	"	12/75	.3-.7
22	3,900,000	700	99.8	"	12/75	0.5-3.0
23	148,000	675	99.5	"	10/74	0.52
24	1,400,000	715	99.1			

(5)→(8)

7.1.5 Electricity Commission of New South Wales, Australia

The Commission has (operating and under order) electrostatic precipitators of efficiencies ranging between 98.5 - 99.5%, on power-plants with ratings of over 5,500 MW. The fuel is black and brown coal with 0.3 - 0.6% S. All the units (except for 4 x 30 MW units installed at the economiser outlet) operate at about 275^{0}F and have about 300-500 ft.^{2}/1000 cfm collecting area and 3 electrical zones in series. The gas flow is in the range 150,000-300,000 a.c.f.m. Most resistivity measurements show values of 10^{13} ohm-cm. All the recent installations have been based on pilot-plant tests and it appears for these coals that, under 1% S concentration the fly-ash behaviour is not dependant to any extent on the sulphur content of the coals. The Commission believes that some of the keys for handling "difficult" fly ashes are:

i) Adequate size of precipitator

ii) Efficient rapping

iii) Proper gas distribution and interior baffling

iv) Velocities less than 5 ft./sec.

The Commission indicates in one of its reports that the "hot" precipitator mentioned above was not found to be sufficiently attractive economically or technically till the time of writing. They compare the advantages of "hot" precipitators (e.g., economy, reduced maintenance, fewer dust removal problems, more uniform performance due to resistivity changes) with the disadvantages of operating at high temperatures (e.g., much higher volume, more ducting and insulation, depression of migration velocity on low sulphur coals (Fig. 14A) and increased probability of voltage limitation); and conclude that neither "hot" or "cold" precipitators offer a universal solution[(6)] and emphasize the importance of doing pilot-plant tests prior to committing to any one kind of equipment.

7.1.6 Calgary Power [24][28]

Along with pilot-plant testing at their Sundance plant,[24][28] Calgary Power also did similar testing at their Wabamun plant (3 coal-fired units @ 66MW, 150 MW and 300 MW). The coal and fly-ash analyses were as follows:[24]

Coal Analysis	Range, wt.%	Fly-ash Analysis	Wt.%
Moisture	17.64 - 21.75	SiO_2	55.21
Ash	12.39 - 16.16	Al_2O_3	25.05
Carbon	47.65 - 51.83	CaO	11.73
Hydrogen	4.10 - 5.09	Fe_2O_3	3.86
Nitrogen	0.58 - 0.64	MgO	1.63
Sulphur	0.17 - 0.29	K_2O	0.97
Oxygen	10.61 - 12.15	TiO_2	0.80
		Na_2O	0.36
		SO_3	0.20
		P_2O_5	0.17
		Li_2O	0.01

There were considerable problems in precipitating the fly ash at this plant inspite of the similarity in the fly ash analysis to that of the Sundance plant. The only major difference was in the Na_2O content. The resistivity was measured at about 2×10^{12} ohm-cm. @ 350°F. During these tests a typical greenish glow with bright bursts were observed at the collecting electrodes. These indicate back-corona conditions where because of dielectric breakdown, substantial reduction of sparkover voltage and generation of positive ions takes place. These positive ions neutralize the negative ions emitted by the discharge electrodes, causing considerable loss of collecting efficiency.

Based on these observations, further testing of precipitation characteristics, was carried out at higher temperatures; leading to a recommendation for selection of a "hot" precipitator. Some of the design parameters were -- migration velocity (about 0.3 ft./sec); gas velocity (about 5 ft./sec.); collection surface (about 300 ft^2/1000 cfm) and the total gas flow of about 2 million cfm at a precipitator inlet temperature of 775^{o}F. The successful bidder (Research-Cottrell) for the project provided 8 fields in the design. The units are under construction at this time.

7.2. Flue-Gas Conditioning (8) (31)→(34)

As has been described, the conductivity or resistivity of the material being collected is of prime importance. In cases where precipitation is difficult, one technique that has been used to increase precipitator efficiency is termed flue-gas "conditioning". This method adds trace amounts of a compound into the flue-gas to modify some of the properties and to bring them into the range of good precipitation. The conditioning agents that have been used include Sulphur Trioxide, Ammonia, Water, Ammonium Sulphate, Sulphamic Acid, Amines, etc., with the first two named agents being most frequently used so far.

7.2.1. Ammonia Conditioning (3)(8)(31)

Results of tests done on some of the power plants of the TVA system (3) are shown below:

Plant	Coal %S	Gas temp. °C	Injected NH_3 ppm.	Fly ash resistivity ohm cm	Flue gas concn, ppm		Fly ash properties			Small particle concn, no./cm^3
					SO_2	NH_3	SO_3 wt. %	NH_3 wt.%	pH	
Widows Creek	0.9	132	0	4×10^{11}	5	0.6	0.22	0.01	5.2	
			10	4×10^{11}	1	0.8	0.18	0.04	5.4	
Bull Run	1.2	127	0	3×10^{10}	2	0.3	0.31	0.01	4.5	2.4×10^6
			7	4×10^{10}	1	0.3	0.33	0.05	4.5	9.8×10^6
Widows Creek	3.5	132	0	1×10^8	11	0.1	1.24	0.01	10.0	1.2×10^7
			20	3×10^8	3	0.1	1.31	0.12	10.0	3.1×10^7
Gallatin	4.0	143	0	4×10^8	1	1.0	1.40	0.21	8.6	6.1×10^7
			20	3×10^8	1	1.0	1.40	0.21	8.6	6.1×10^7

Ammonia was injected at Concentrations of 7-20 ppm by vol.. One of the hypotheses to emerge from these tests was, that instead of altering the resistivity of the fly-ash, ammonia was modifying the electrical properties of the flue-gas itself. Specifically it produces a "space-charge effect" of the electrical field by flowing between the corona wires and the collection electrodes. It is thought that the ammonia reacts with the SO_3 and water vapour of the flue gas to form particulate Amm. Sulphate or bisulphate and

subsequently, charging of these particles takes place. It was found in tests that the concentrations of NH_3 and SO_3 had indeed decreased further downstream; and the fly-ash collected showed evidence of the reaction products of these two gases.

Another conclusion derived from these tests was regarding the increase in the cohesiveness of the fly-ash particles lowering the re-entrainment of the ash deposited. It was found that with ammonia injection downstream from the preheater, large aggregates of solids materials accumulated near the injection nozzles. Photomicrographs have shown that conditioned ash particles are bridged by feathery (possibly) ammonia sulphate material.

The change in efficiency from Ammonia conditioning is shown below:(3)

Plant	Coal %S	Injected NH_3 concn, ppm	Fly-ash concn, g/m^3		Efficiency %
			Inlet	Outlet	
Widows Creek	0.9	0	15.2	1.54	90
		10	16.7	0.28	98
Widows Creek	3.5	0	-	-	87
		10	-	-	99
Gallatin	High	0	-	0.35	
		18	-	0.07	

It should be noted that the changes in efficiency due to NH_3 as described were thought to take place only when moderate (2-11 ppm) SO_3 concentrations are available.

The following shows the experience at 4 boiler-plants where Koppers Company(31) did some tests with NH_3 conditioning. The following table lists some results obtained by adding 15 ppm ammonia at 700°F.

Station	A	B	C_1	C	D
Airheater Outlet temperature °F	400	300	290	290	400
Untreated dust resistivity, ohm-cm	10^{12}	10^{12}	5×10^{8}	5×10^{8}	3×10^{11}
Untreated dust, pH	5.5	5	3.5	3.5	3
Treated dust resistivity, ohm-cm.	10^{11}	5×10^{11}	10^{14}	10^{16}	5×10^{10}
Treated dust, pH	7	6	4.5	4.5	4
Pptr. power increase, %	80	40	70	40	150
Pptr. residual decrease, %	85	40	70	30	60
Airheater Δ P increase	None	Rapid	Medium	Medium	None

The tests can be summarized as follows:

1. Precipitator power input and collection efficiency always improved but to varying extent.
2. All untreated dusts were found to be acidic and the conditioned ash always becomes less acidic.
3. No correlation could be established between effectiveness and initial ash resistivity, nor between ammonia injection and treated ash resistivity.
4. Except for those boilers with preheater exit temperatures of 400°F, air heater pluggage resulted from the ammonia injection.
5. Increasing the ammonia injection rate to above 15 ppm. was unrewarding.
6. The reactions and their resultant effects on downstream equipment are less than simple and these are not yet understood in sufficient depth.

Ammonia conditioning was also done at the Tallawara station, New South Wales, Australia. The fly-ash acidity was about 3.5-4. In the initial pilot-plant tests at Tallawara an injection rate of 15-20 ppm anhydrous ammonia, raised the efficiency from about 85% to 98%. In the full size #5 pptr. of the station, an injection rate of 17 ppm, increased the efficiency from 80% to 96%. It was noted that a 50-100% increase in electrode potential and a corresponding decrease in electrode current were maintained consistently and tended to persist hours after the stoppage of injection. It was noted however, that no appreciable decrease was caused in the resistivity of the fly-ash from the conditioning. The moderate success of the tests have meant the permanent ammonia conditioning installations on 2 - 100 MW units.

7.2.2 SO_3 Conditioning (8) (30) (32)

The SO_3 (produced in the flue-gas from the combustion of coal) combines with water present to form sulphuric acid. It is thought that the amount of this acid condensing on the particles in the flue gas influences the resistivity and hence the collection of the particles. As the resistivity is noted to be high with low SO_3 concentrations, conditioning or addition of SO_3 is done by various methods. Several prerequisites are necessary for successful flue gas conditioning. First, the precipitator must be capable of meeting compliance tests at design conditions with high sulphur coal or be capable of being modified to improve its performance to a satisfactory level. Second, the SO_3 must be distributed properly into the flue gas to treat the fly-ash completely before it enters the precipitator. Normally, the proper location of the probes and nozzles to obtain optimum distribution requires a flow model study.

The third requirement is that the SO_3 equipment must be simple to operate and capable of automatically controlling the SO_3 feed depending on boiler load. It must also be capable of being on line from a cold start rapidly.

Generally this type of conditioning is achieved by the 3 following commonly used methods:[32]

i) Injection of vapourized SO_3

ii) Vapourization/Dissociation of H_2SO_4

iii) Catalytic conversion of SO_2 to SO_3, followed by injection of the SO_3.

These methods are being described by way of operating experiences at some of the installations:

1) <u>Public Service of Colorado</u>[30][36]

The optimum injection rate is determined by injecting 18-25 ppm SO_3 and detecting any excess in the outlet. The company used an acid vapouriation system on 4 boilers, an acid dissociation system on 1 boiler and injection of stabilized liquified SO_3 in 3 boilers. The installations have operated for over 3 years.

Fig. 15 shows the system for vapourizing 92° Baume sulphuric acid at 550°F into a stream of electrically heated air. This vapourizes, decomposes and sweeps the acid into the duct. The temperature of the air is maintained constant, the air flow to the boiler controls the quantity of the acid vaporized. Fig. 16 shows the system where hot gases are produced in a pressurized gas burner and sweep the acid Vaporizer at 1000°F, dissociating the acid. The products of combustion, SO_3 and water are injected into the gas stream. The acid feed to the vaporizer is controlled by the boiler fuel supply. Fig. 17 shows the SO_3 injection system used on 3 boilers. The stabilized SO_3 (to avoid conversion to other forms) is metered into the steam heated vaporizer. The resultant SO_3 vapour is picked up and transported to the duct work by electrically heated air at 290°F. The stabilizer does not vaporize and is reclaimed from the base of the vaporizer The tests on the conditioning system are summarized below:

UNIT	NAMEPLATE RATING	GUARANTEED EFFICIENCY %	Without OBS. EFF.%	With Gas Conditioning OBS. EFF.%
Cherokee #1	100 MW	90.0	57.9	72.6
Cherokee #2	110 MW	94.2	94.0	95.2
Cherokee #3	150 MW	87.0	37.5	51.4
Cherokee #4	350 MW	98.05	86.0	90.7
Arapahoe #2	44 MW	97.5	77.5	96.2
Arapahoe #3	44 MW	90.0	81.0	94.5
Arapahoe #4	100 MW	87.0	67.3	77.3
Cameo #2	44 MW	87.0	54.1	95.0

Operating problems included condensation causing accelerated corrosion and ash build-up. Additional insulation and strip heaters to maintain higher temperatures were used to alleviate the condensation problems. The ash build-up on the injection nozzles in the duct was reduced by maintaining constant flow in the nozzles even if the acid system was not in use. The gas conditioning systems are believed to be high maintenance items. The liquid SO_3 is a dangerous fluid to have in storage and the stabilized kind is quite expensive. It should be noted that despite the increased efficiency, some units have had to be back-fitted with U.O.P. particulate scrubbers in order to meet required/desired efficiencies.

2) <u>Colorado Springs Public Utilities</u> - Martin Drake Plant (37)

Units 5 (44 MW) and 6 (60 MW) of this 7-unit plant have been equippped with gas conditioning equipment. The fuel is Northern Colorado 0.8% S coal.

Unit 5 is fitted with a Wahlco system which catalytically converts liquid SO_2 to SO_3 and injects it by a number of lances into the flue gas

stream at a concentration of 20-30 ppm. While too many details are not available it appears that the system has been reliable and relatively trouble-free. It is reported that sometimes it has been difficult to obtain a supply of SO_2.

Unit 6 is fitted with a U.O.P. sulphuric acid evaporator, injecting SO_3 at 15-20 ppm concentration. It seems that due to several reasons, such a short residence time for SO_3, poor gas distribution and poor flue gas velocity profiles, this system has not worked as well as could be expected. The piping is glass-lined to avoid low temperature corrosion from SO_3 gas, and along with the precautions that have to be taken in the handling of H_2SO_4, the system is less than convenient to work with.

3) Commonwealth Edison Company[(3)]

The first installation (a Research-Cottrell Unit) was at 230 MW pulverized coal fired boiler at State Line Station. The analyses of the coal and the fly-ash are shown below:

"As received" coal analysis (% by weight)	
Moisture	10.8-12.3
Sulfur	0.52-0.86
Ash	10.94-14.43
Gram-Cal/gram	5,358-5,654
(Btu/lb)	(9,644-10,176)
Ash analysis (% by weight)	
Silica	31.6-39.7
Alumina	16.9-19.0
Iron oxide	10.6-18.8
Titanium oxide	0.5_0.7
Calcium oxide	15.3-18.8
Magnesium oxide	3.0-316
Potassium oxide	1.0-1.6
Sodium oxide	0.64-0.74

The Research-Cottrell experimental system shown in Figure 18 consists of liquid sulfur feed to a pan type burner where the sulfur dioxide is formed by combustion. The sulfur dioxide is then passed through an electric heater and a two-pass catalytic converter, with interstage cooling, which converts over 90% of the SO_2 to SO_3. The SO_3/air mixture of about 10% SO_3 is then piped through an insulated manifold to the probe and nozzle system located internally in the ducts leading to the electrostatic precipitator.

It was soon obvious that the capacity of the gas conditioning system was inadequate. The experimental system had to be modified by reducing the total system pressure drop, and increasing the combustion air rate. This was accomplished by increasing the probe nozzle areas. In addition, provision was made to spike the sulfur dioxide combustion gases with vaporized SO_2 supplied from a liquid SO_2 storage tank.

Testing of the system included measuring particulates and gas composition, fuel and ash analysis, and precipitator power input. Gas temperatures varied from 144^o to 154^oC (292^o-345^oF) at the precipitator inlet with moisture content ranging from 8.4 to 10.7%. Oxygen content of the gas was 5 to 6% roughly equivalent to 35% excess air. Particulate inlet loadings ranged from 5.95 g/m^3(stp) to 7.32 g/m^3(stp) (2.6 to 3.2 gr/scf).

The effect of the SO_3 concentration on precipitator efficiency is shown in Figures 19 and 20. The corona power input exhibited a great improvement with flue-gas conditioning. Without conditioning, sparking limits the power input level to about 25 watts/1000 acfm. A ten-fold increase in power to about 250 watts/1000 acfm accompanied SO_3 addition to about 40 ppm. Additional SO_3 injection above this level did not appear to improve the power input to the precipitator.

Since the basic purpose of the prototype system was to prove that normal precipitator performance could be obtained by SO_3 injection, the test program was considered successful, even if all of the objectives, such

as a reliable gas analysis were not achieved.

It was also concluded that increased SO_3 levels are required when treating highly basic fly ash such as that produced from Arch Mineral.

The second installation, a liquid SO_3 system installed on a pulverized coal fired, 325 MW boiler at Waukegan Station, was designed for 20 ppm SO_3 injection. The system was designed with a spare evaporator which will now be needed to operate at the desired SO_3 concentration. Unfortunately, the piping could not be changed and the system, designed to carry 8% SO_3 - air mixture to the probes will be transporting a 15% mixture. This could increase the possibility of a chemical corrosion problem if the dry air system functions marginally. The system supplied by Chemitron Corporation was placed in operation and is capable of automatically following the boiler load.

The system, as shown schematically in Figure 21 consists of a pressurized liquid SO_3 storage tank which feeds two electrically heated evaporators. Heated dry air is added in the evaporators and the air and gaseous SO_3 is then routed through a heat-traced, insulated pipe to the probe and nozzle system located internally in the ducts before the electrostatic precipitator.

Based on the study of the existing systems the company has indicated that a sulfur burner type system would be desirable because of initial cost, operating cost, availability of raw material, storage and handling, and simplicity of operation. Ten units ranging in size from 120-620 MW have been committed to SO_3 conditioning.

4) Central Electricity Generating Board - U.K.[5]

The first full-scale installation was at the Kincardine Station where the efficiency increased from 82% to 99% with the injection of about 15 ppm SO_3. The coal and the ash analysis were as follows:

Coal Analysis (% by Wt.)		Ash Analysis (% by Wt.)	
Moisture	13.67	Moisture	Nd
C	54.67	Combustibles	1.50
H_2	3.52	SiO_2	48.80
S	0.47	Al_2O_3	41.76
Ash	19.18	Fe_2O_3	3.04
Cl	0.03	CaO	2.49
		MgO	0.66
		TiO_2	1.00
		P_2O_5	1.04
		Cl	0.23
		Water Solubles	0.65
		Sulphates	0.16
		Alkalis	0.72

5) The Electricity Commission, New South Wales (5)

100 ppm. SO_3 injection rate was used in tests and the efficiency increased from 80% to 90% at the Tallawara Station of the Commission in Australia.

The analyses were:

Coal Analysis (% by Wt.)			Ash Analysis (% by Wt.)	
Moisture	8.09		Moisture	0.13
C	63.88		Combustibles	3.64
H_2	4.18		SiO_2	71.20
S	0.38		Al_2O_3	20.78
Ash	16.35		Fe_2O_3	8.20
Cl	0.03		CaO	0.78
			MgO	0.08
			TiO_2	0.88
			P_2O_5	0.10
			Cl	0.16
			Water Solubles	1.35
			Sulphates	0.18
			Alkalis	1.01

6) Calgary Power (24)

At the Wabmun plant of this power company, stabilized SO_3 (Allied Chemical's "Sulfan"), was tried under pilot-plant conditions. (See section on "Sodium Conditioning" for details on coal and fly-ash analysis).

Immediate effects on voltage and current characteristics were noted. However it was seen that the conditioning had also a "lingering" effect on the layer precipitated on the collecting electrodes which had to be cleaned by hosing. The efficiency increased from 62% to 95.6% while the change in effective migration velocity was from 0.28 to 0.97 ft./sec. It should be noted that the on the basis of technical and economical analysis the company decided to choose a "hot" precipitator for this station.

7.2.3 Moisture Conditioning (8)

Conditioning of gases by steam injection or by water sprays has been tried as a convenient method to raise the dielectric strength of the dust layer and to reduce the viscosity of the gas. An extensive series of tests for humidity conditioning of gases was conducted at Pyrmont Station of the Electricity Commission of New South Wales. It was found that steam conditioning was uneconomical, whereas injection of water caused carry over of droplets into the precipitator and also condensation on various sections of the precipitator causing serious dust caking and corrosion.

It should however be noted that different fly-ashes behave very differently and in many cases the temperatures may be high enough to keep the water from condensing. The rate of water adsorption on particles varies directly with the moisture content of the gas and inversely with the temperature, so that conditioning by humidification is more effective at lower temperatures.

7.2.4. Sodium Conditioning (24)

Recent research has pointed out the effect of sodium salt conditioning on the collection efficiency. Two analyses of coals and ashes from Sundance and Wabamun Stations of Calgary Power, Alberta are shown:

Coal Analysis	(Sundance Station) (% by Wt.)	(Wabamun Station) (% by Wt.)
Moisture	19.01 - 20.89	17.64 - 21.75
Ash	13.80 - 17.88	12.39 - 16.16
Carbon	46.47 - 50.22	47.65 - 51.83
Hydrogen	4.66 - 5.12	4.10 - 5.09
Nitrogen	0.45 - 0.63	0.58 - 0.64
Sulphur	0.15 - 0.22	0.17 - 0.29
Oxygen	9.79 - 10.64	10.61 - 12.15

Ash Analysis	(Sundance Station) (% by Wt.)	(Wabamun Station) (% by Wt.)
SiO_2	50.38	55.21
Al_2O_3	26.11	25.05
CaO	13.07	11.73
Fe_2O_3	4.64	3.86
MgO	0.97	1.63
K_2O	1.00	0.97
TiO_2	0.91	0.80
Na_2O	2.26	0.36
SO_3	0.41	0.20
P_2O_5	0.23	0.17
Li_2O	0.01	0.01

The Sundance ash had a resistivity of about 10^{10} ohm-cm and could be precipitated without too much trouble. The Wabamun fly-ash had a resistivity of 10^{12} ohm-cm and was difficult to separate. Sodium salt feed-rates of up to 4 kg./hr. decreased the resistivity to about 10^{10} ohm-cm. Further research on this is indicating that alkali metal ions in general are good charge carriers, and presence of iron further enhances the effect of sodium in lowering resistivity. While the effects of sodium on the high resistivity fly-ash has been demonstrated with many different low-sulphur Western coals, it has not been shown to be economical so far.

7.3 Blending

While not too many instances of successful blending of high and low-sulphur coals to achieve good precipitator efficiency and/or to control SO_2 emissions are known, Ontario Hydro is presently engaged in a series of tests in which 2-types of coals with analysis shown below are being blended. To date no appreciable increase has been noted in the very low outlet loading from the precipitators which have been installed

after the air-preheaters in the common manner.

Analyses	Coal #1	Coal #2
Moisture (%)	4.96	6
Ash (%)	8.78	17
Volatile Matter (%)	35.52	21
Fixed Carbon (%)	50.74	56
Sulphur (%)	2.42	0.3
Higher Heating Value (Btu /lb.)	13,115	12,000

Analyses	Fly-ash #1	Fly-ash #2
SiO_2	39.9	46.8
Al_2O_3	23.2	31:0
Fe_2O_3	23.5	1.6
TiO_2	0.9	1.7
P_2O_5	0.16	0.69
CaO	6.9	0.89
MgO	1.7	2.3
Na_2O	0.8	0.81
K_2O	1.3	0.47
SO_3	4.4	0.22
Loss on Ignition	10	1.0

8.0 COSTS

8.1 Precipitator (34)

While no current figures are available presently on costs associated with "hot" precipitators, a comprehensive study of the costs associated with the precipitators on 30 T.V.A. power plants for the years 1969-71 was released some time ago. This was reported in J.A.P.C.A., April, 1974, and was titled "Costs of Air Cleaning with Electrostatic Precipitators at T.V.A. Steam Power Plants, " authored by J.R. Benson & M. Corn. The following information on the T.V.A. Precipitators has been taken from that article:

Table 1.

Name	Nominal plant capacity, MW	% ash to Coll's	Coal analysis FY 71: Ash, %	Coal analysis FY 71: Heating value, Btu/lb	Present design: E_m[a], %	Present design: E_e[b], %	Present design: E_t[c], %	Present design: Emission, lb/10^6 Btu	Present estimated actual performance: E_m[a], %	Present estimated actual performance: E_e[b], %	Present estimated actual performance: E_t[c], %	Present estimated actual performance: Emission, lb/10^6 Btu
Allen 2-3	600	30	12.2	11,180		99	99	0.033		95	95	0.164
Bull Run 1	900	80	15.8	11,380		99	99	0.111		81	81	2.110
Colbert 1	200	80	14.5	11,260	67	97	99	0.103	50	96	98	0.206
Colbert 5	500	80	15.0	11,290		90	90	1.063		50	50	5.31
Cumberland 1-2	1300	80	15.0	11,200		99	99	0.107				
Gallatin 1-2	500	80	17.4	10,520	74	95	98.7	0.172	60	92	96.8	0.423
Gallatin 3-4	550	80	17.2	10,550	47	95	97.4	0.339	40	90	94	0.782
John Sevier 1-4	800	80	16.2	11,320	67	98.5	99.5	0.057	50		50	5.724
Johnsonville 1-6	750	80	13.7	11,090	70		70	2.965	60		60	3.924
Johnsonville 7-10	600	80	13.8	11,120	81	98.5	99.7	0.030	70		70	2.978
Kingston 1-4	600	80	18.9	10,820	60	95	98	0.280	60	80	92	1.118
Kingston 5-9	1000	80	18.9	10,830	60	95	98	0.280.	50	85	92.5	1.05
Paradise 1-2	1400	30	18.9	10,210		98	98	0.111		95	95	0.277
Paradise 3	1100	30	18.8	10,240		98	98	0.110		95	95	0.275
Shawnee 1-10	1500	80	14.8	10,700	66	90	96.6	0.376	60	90	96	0.442
Watts Bar A-D	240	50	12.4	11,705		95	95	0.265		95	95	0.265
Widows Creek 1-6	750	80	19.8	10,670	70		70	4.454	60		60	5.938
Widows Creek 7	500	80	18.2	10,730		99	99	0.136		95	95	0.678
Widows Creek 8	500	80	18.2	10,790		90	90	1.349		50	50	6.75
Allen 1	300	30	12.2	11,180		90	90	0.327		70	70	0.982
Colbert 2, 3 & 4	600	80	14.5	11,260	67		67	3.40	50		50	5.15

[a] E_m = mechanical collector efficiency.
[b] E_e = electrostatic collector efficiency.
[c] E_t = overall efficiency.

Table 2.

Plant & unit number	Esp installation year	Average total cost \$/cfm-yr	Average total cost \$/cfm-yr-eff
Bull Run 1	1966	0.269	0.290
Colbert 5	1962	0.252	0.373
Gallatin 1	1969	0.376	0.401
Gallatin 2	1970	0.393	0.421
Gallatin 3	1970	0.366	0.402
Gallatin 4	1969	0.377	0.418
Kingston 1	1960	0.284	0.336
Kingston 2	1960	0.251	0.291
Kingston 3	1960	0.272	0.319
Kingston 4	1960	0.333	0.384
Kingston 5	1960	0.223	0.259
Kingston 6	1960	0.172	0.198
Kingston 7	1960	0.223	0.256
Kingston 8	1960	0.218	0.258
Kingston 9	1960	0.219	0.249
Paradise 1	1967	0.446	0.462
Paradise 2	1967	0.454	0.471
Paradise 3	1969	0.570	0.592
Shawnee 1	1970	0.329	0.424
Shawnee 2	1969	0.319	0.407
Shawnee 3	1969	0.321	0.372
Shawnee 4	1969	0.316	0.359
Shawnee 5	1970	0.340	0.450
Shawnee 6	1969	0.320	0.369
Shawnee 7	1970	0.332	0.386
Shawnee 8	1970	0.332	0.388
Shawnee 9	1969	0.322	0.372
Shawnee 10	1969	0.320	0.369
Widow Creek 7	1960	0.308	0.404
Widow Creek 8	1964	0.314	0.452

TABLE 3.

Number of units	Year of esp installation	Average mean of total cost/yr. $/cfm-yr	$/cfm yr-eff.
10	1960	0.250	0.295
1	1962	0.252	0.373
1	1964	0.214	0.451
1	1966	0.269	0.290
2	1967	0.450	0.467
9	k969	0.360	0.407
6	1970	0.349	0.412

TABLE 4.

	Range of Cost ($.cfm-yr)					
	1969		1970		1971	
	High	Low	High	Low	High	Low
Annualized capital cost	0.299	0.063	0.289	0.063	0.289	0.063
Total operating cost	0.015	0.005	0.135	0.007	0.135	0.009
Total maintenance cost	0.210	0.040	0.452	0.097	0.354	0.080
Total cost	0.394	0.153	0.643	0.178	0.700	0.171

TABLE 5.

	Range of normalized Cost ($/cfm-yr-eff)					
	1969		1970		1971	
	High	Low	High	Low	High	Low
Annualized capital cost	0.308	0.066	0.325	0.072	0.325	0.075
Total operating cost	0.026	0.077	0.138	0.009	0.139	0.011
Total maintenance cost	0.215	0.053	0.156	0.098	0.442	0.093
Total Cost	0.429	0.161	0.660	0.218	0.740	0.201

The background information for the costs is detailed as follows:

Annualized capital costs are estimated by depreciating the capital investment (total installed cost) over the expected life of the control equipment and adding the capital charges (taxes, interest and insurance). Adding the recurring maintenance and operation costs to this figure gives a total annualized cost of control.

The simplifying assumptions for computing the total annualized capital cost are as follows:

1. Purchase and installation costs are depreciated over 15 years, a period assumed to be a feasible economic life for control devices.
2. The straight line method of depreciation (6 2/3% yr.) is used because it is the most common method used in accounting practices. This method has the simplicity of a constant annual writeoff.
3. Capital charges -- which include interest, taxes, insurance and other miscellaneous costs -- are assumed to be equal to the amount of depreciation or 6 2/3 percent of the control equipment installed. Therefore, depreciation plus these other annual charges amount to 13 1/3% of the initial capital cost of the equipment.

Maintenance cost is the expenditure required to sustain the operation of a control device at its designed collection efficiency.

The only operating cost considered in the operation of electrostatic precipitators is the power cost for ionizing the gas. The power cost varies with the efficiency and the size of the equipment. Power costs are given in $/kw-hr with a typical value $.011/kw-hr with a range from $.005 to .020/kw-hr.

The assumptions used in calculating annual operation and maintenance costs for a high-voltage precipitator are as follows:

1. Annual operating time -- 8760 hr.
2. Electrical power requirements:

   0.00019 kw/acfm for low efficiency

   0.00026 kw/acfm for medium efficiency

   0.00034 kw/acfm for high efficiency

3. Maintenance cost = $0.02/acfm.
4. Power Cost = $0.911/Kw Hr.

The average total cost (TABLE 2) (expressed as $/cfm-yr.) shown is the average of the total, i) annualized capital cost

ii) maintenance costs, and

iii) operational costs for each unit for the years 1969-71.

The costs expressed as $/cfm-year-eff. in the same table are arrived at by dividing the $/cfm-year costs as described above by the estimated annual efficiencies of such precipitators extracted from U.S. Federal Power Commission Reports.

The "ranges of normalized costs" (TABLE 5) expressed as $/cfm-yr-eff., in the various cost assignment categories for the thirty generating units and control systems as shown, differ from those as "range of costs" (TABLE 4) because the estimated annual efficiency for each ESP varied during the years under discussion. Thus, costs are greater during years when collection efficiency is lower. In almost all cases, the estimated annual efficiency decreased in 1971, which raised costs in that year. The reason for this decrease was unknown.

Maintenance costs seem to be the main reason for large differences in the total costs of various units.

8.2 Conditioning Costs (33)

The following cost data for conditioning of flue-gases are

taken from an article "Condition fly-ash with Synthetic SO_3," by E.B. Morris and J.L. Schumann and published in Power, July, 1974. The synthesized SO_3 system refers to a patented process in which the liquid SO_2 is oxidized to SO_3 and injected in the gas stream.

Costs for conditioning flue gas in a 500 MW plant

Cost item	H_2SO_4 evaporation	SO_3 evaporation	Synthesized SO_3
Installed capital cost	\$784,000	\$345,000	\$350,000
Operating Costs			
66 deg Be H_2SO_1 (@ \$50/ton)	62,000	-	-
Liquid SO_3 (@ \$103/ton)	-	118,600	=
Liquid SO_2 (@ \$95/ton)	-	-	78,500
Natural gas (@ \$0.40/1000 cuft.SC)	4,000	-	-
Steam (@ \$1/1000lb)	-	500	-
Electricity	1,600	3,800	16,800
Capital (@ 14.5%)	113,700	50,025	50,750
Labor and maintenance (@ 5%)	39,200	17,250	17,500
Total operating costs	\$220,500	\$190,175	\$163,550
Cost in mills/kWh	0.0632	0.0544	0.0435

9.0 DISCUSSION

The review has briefly presented the general principles of particulate collection by electrostatic precipitators and the special problems associated with collection of fly-ash from combustion of low-sulphur coals. As has been indicated there is no universal solution to low-sulphur coal fly-ash collection. Any of the following - cold or hot precipitators; gas conditioning with water, NH_3, SO_3 or some other chemical; blending the low-sulphur coal with high-sulphur coal may provide the answer for a particular station. It is becoming usual to conduct an intensive pilot-testing at the plant to arrive at the recommendation for the equipment to be used.

As use of this type of coal becomes more and more common, in order to provide an input, it will be of importance to the Ministry to obtain details about the various factors involved in the selection of the system, any special design features, the operating experience in general any problems in particular, and most important of all, the economic feasibility and viability at different locations with different types of coals.

In the time allocated for this preliminary report, it has not been possible to receive information about all the manufacturers of control equipment. Information is also not yet complete about the various research work sponsored by the control agencies. It is expected that all this material could be included in a subsequent report.

10.0 CONCLUSIONS

From the information collected so far, it appears that most of the precipitators referred to in this report, have succeeded in meeting their design objectives. However, it is known that some are giving rise to complications for reasons not quite clear at the moment.

It may be to the advantage of the Ministry personnel to be cognizant and aware of the reasons and rationale in the selection of the major units, in as much as, this input may be required when such a selection might be made in the local area. It will also be important to monitor the continuing performance of the operating units, so that any special problems that arise with time may be pointed out.

With this in view, the major units which have been installed should be visited and the details should be reported in a subsequent report.

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Section A.

Information to be Supplied by Purchaser

General Information

1) Purchaser ______________ Address ______________
   a) User (if different from above) ______________
      Address ______________
2) Site Location ______________
3) Individual, title and address to whom proposal is to be sent: ______________
   a) Number of copies of proposal to ______________
4) Date proposal is to be submitted ______________
5) Purpose of proposal: budgetary or firm? ______________
6) Is formal proposal required, or priced letter? ______________
7) Equipment delivery requirement date ______________
8) Bid Basis: FOB shipping point; FOB cars destination; FOB shipping point FA to site; other ______________

Section B.

Plant Process

1) Process to which precipitator will be applied ______________

   Furnace, boiler, kiln, other ______________
   Design data: Type ______________
   Make ______________
   Output: continuous rating ______________
   peak rating ______________
2) Description and analyses of raw material or fuel ______________
3) Expected variations in raw material input to furnace, etc. ______________
4) Description and rating of existing collector equipment, if any ______________

Section C.

Operating Conditions

1) Gas volume at precipitator inlet as measured by Pitot tube:
   @ Continuous rating, actual cfm ________ @ ________ °F, ________ psia
   @ Peak rating, actual cfm ________ @ ________ °F, ________ psia
   Moisture content in gas % by volume ________ or % by weight ________
   Volume for which precipitator efficiency guarantee is to be based, continuous or peak ______________
2) Gas analysis, Orsat or calculated ______________
3) Chemical analysis of dust or liquid to be collected; include specific gravity, bulk density of dust with two values, one for volumetric capacity of dust hoppers and the other for structural design. ______________
   a) Is a representative sample of dust available? (yes) ________ (no) ________
4) Particle size analysis ______________
5) Dust load at precipitator inlet:
   @ Continuous rating, actual grains/cubic foot ______________
   @ Peak rating, actual grains/cubic foot ______________
   Conditions on which precipitator performance guarantee is to be based, continuous or peak ______________
6) Barometric pressure or elevation at plant site ______________

Section D.

Performance

1) Collection efficiency ________ %
2) Maximum outlet concentration allowed ________ gr/acf

Section E.

Layout Drawings

1) The precipitator will be installed generally in conformance with the attached drawing number ________
2) Maximum permissible pressure drop through equipment being supplied by bidder: inches W.C. ________

3) Indicate single or multiple chamber requirement ____________________

Section F.

Design Features
The precipitator will have the following structural design features:
1) Operating pressure ________ W.C. Negative - Positive
2) Design pressure ________ W.C. Negative - Positive
3) Design temperature ________ °F
4) Casing material ____________________ ; Thickness ____________________
5) Hopper material ____________________ ; Thickness ____________________
6) Minimum hopper valley angle ________ ° from horizontal
7) Type of bottom: hoppers (pyramidal, bunker) drag scraper,
wet ____________________
Specify storage capacity ____________ hours

Section G.

Auxiliary Equipment By	Purchaser	Bidder	Description
Supporting steel			
Access facilities			
Transition nozzles			
Ductwork & expansion joints			
Gates & dampers			
Hopper dust valves & conveyors			
Control room			
Instrumentation			
Fans & auxiliaries			
Motor control center			
Other			

Section H.

Erection Scope
1) Erection by: purchaser or bidder ____________________
2) Erection supervisor services; separate quote or include in material price
____
3) Start up and test engineer services; separate quote or include in equipment price
____
4) Travel and subsistence costs for erection forces by purchaser or bidder
____
5) Erection period: Starting date ____________ Completion date ____________
6) Site information:
Storage area; size in sq. ft. and distance from job site ____________________
____
Availability of closed storage area ____________________
Freedom of crane area ____________________
Overhead obstacles ____________________
Distance utility sources are from job site ____________________
Is truck roadway and/or railroad right-of-way to storage area ________ ; to job site ________ ;
if not, distance from unloading point to storage area
____

7) Scope of erection responsibility:	Purchaser	Bidder
Foundations (piles or slabs)		
Material unloading to storage		
Material rehandling to job site		
Low voltage wiring		
Insulation (type, etc.)		
Ductwork, gates, expansion joints, etc.		
Lighting		
Erection equipment: cranes, welding machines, etc.		
Erection facilities: field office, change shanty & sanitary facilities		
Erection utilities: air, water, light		
Field painting: (complete or touch-up)		
Electrical substation		

Attach description of above items if not covered by plant standards.
8) Available electric power
For Precipitator ________ Volts, ________ Phase, ________ Cycle, ________ KVA
For Erection ________ Volts, ________ Phase, ________ Cycle, ________ KVA
For Controls & Instrumentation ________ Volts, ________ Phase, ________ Cycle, ________ KVA
9) Plant standards attached ____________________
10) Other remarks or comments:

Information to be Supplied or Confirmed by Manufacturer

SECTION 1 - Performance Data

a. Operating Conditions

1. Gas Flow Rate (by volume)
2. Gas Temperature
3. Dust Concentration
4. Gas-Water Vapor
5. Pressure
6. Dust Reinjection

b. Performance at Operating Conditions

1. Guaranteed Efficiency
2. Expected Efficiency
3. Guaranteed Residual
4. Pressure Drop
5. Gas Velocity through Precipitator
6. Time of Treatment

SECTION 2 - Structural Design Parameters

a. Structural Design Code
b. Wind Load
c. Live Load
d. Seismic Zone
e. Dust Bulk Density-Structural
f. Platform Load
g. Snow Load
h. Temperature
i. Pressure

SECTION 3 - Mechanical Design Data

Precipitator - Arrangement and Casing
a. Number of Precipitators
b. Number of Chambers per Precipitator
The following is for one precipitator only
c. Number of Fields
d. Number of Power Supplies per Field
1st Field
2nd Field
3rd Field
....
e. Number of Bus Sections per Field

Field	Series	Parallel	Total
1st			
2nd			
3rd			
...			

f. Total Number Bus Sections
g. Gas Passages
h. Spacing of Gas Passages
i. Precipitator Casing Dimensions
j. Number and Type Hoppers
k. Hopper Slope
l. Hopper Material
m. Casing Material
n. Access Doors (Numbers and Location)
1. Precipitator Roof and Sides
2. Insulator Housings-Penthouse
3. Hoppers
4. Duct Transitions
o. Gas Distribution Devices

SECTION 4 - Collecting Surfaces

a. Type
b. Gas Baffles - Size and Location on Surfaces
c. Size and Number Surfaces
d. Collecting Surface Thickness
e. Active Collecting Surface Area

SECTION 5 - Discharge Electrode System

a. Discharge Electrode - Diameter and Type
b. Effective Length per Electrode
c. Number Electrodes per Gas Passage
d. Total Number Electrodes
e. Total Effective Length
f. Tensioning Weight and Shape
g. Size of Shroud
h. Method of Attachment
i. Spacing in Direction of Flow

SECTION 6 - Rapping System

a. Type Rapper - Pneumatic, Electric, Impulse or Vibratory
b. Quantity and Type
1. Collecting Surfaces
2. Discharge Electrodes
3. Perforated Plates
c. Weather-tight Rapper Panel - Number and Location
d. Number of Rapper Timers/Panel
e. Rapper Control Variables - Range and Sectionalization by Field
1. Interval
2. Intensity
3. Duration
f. Rapper Electrical Requirements
g. Maximum Instantaneous Power Required

SECTION 7 - Electrical

a. Transformer-Rectifiers
1. Type
2. Number
3. Size
1st Field
2nd Field
3rd Field
....
4. Voltage Rating - Peak and D.C. Average
5. Current Rating Each

	Primary	Secondary
1st Field		
2nd Field		
3rd Field		
....		

6. Output Wave Form
b. Transformer-Rectifier Insulation Fluid
c. High Voltage Switch
d. Transformer-Rectifier Control Cabinet
e. Transformer-Rectifier Control
f. Maximum Ambient Temperature for Transformer-Rectifier
g. Maximum Ambient Temperature for Transformer-Rectifier Control Cabinet
h. Electrical Supply for Transformer-Rectifier
1. Volts
2. Phase
3. Cycle
i. Expected Power Consumption
1. Precipitator
2. Rappers
3. Pressurizing Blowers for High Voltage Bus Ducts
4. Air Heaters for Pressurizing Blowers
j. Total Connected Load (T-R Units)
k. Type of High Voltage Conductor
l. Suspension Insulators
1. Type and Number
2. Manufacturer
3. Dry Arc-Over K.V. RMS
4. Wet Arc-Over K.V. RMS
5. Leakage Distance
m. Interlocks

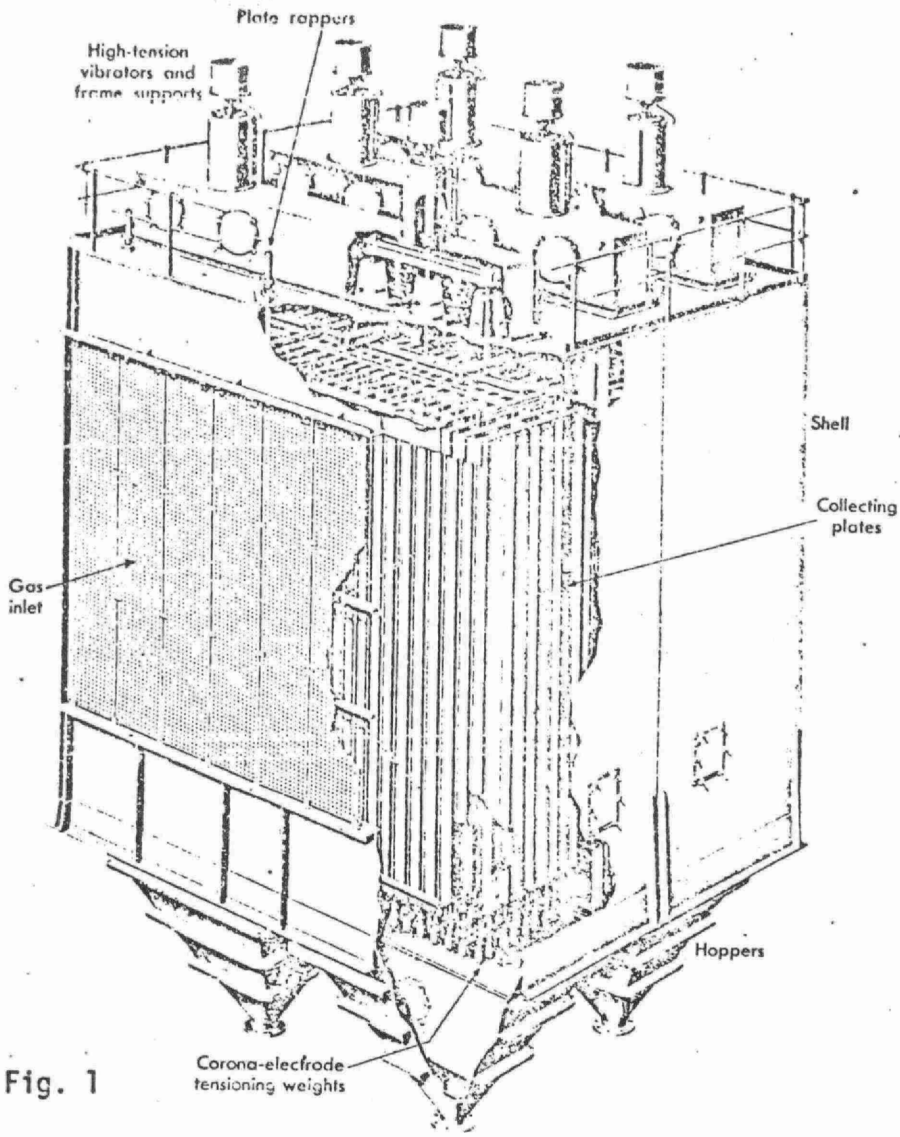


Plate rappers
High-tension vibrators and frame supports
Shell
Collecting plates
Gas inlet
Hoppers
Corona-electrode tensioning weights

Fig. 1

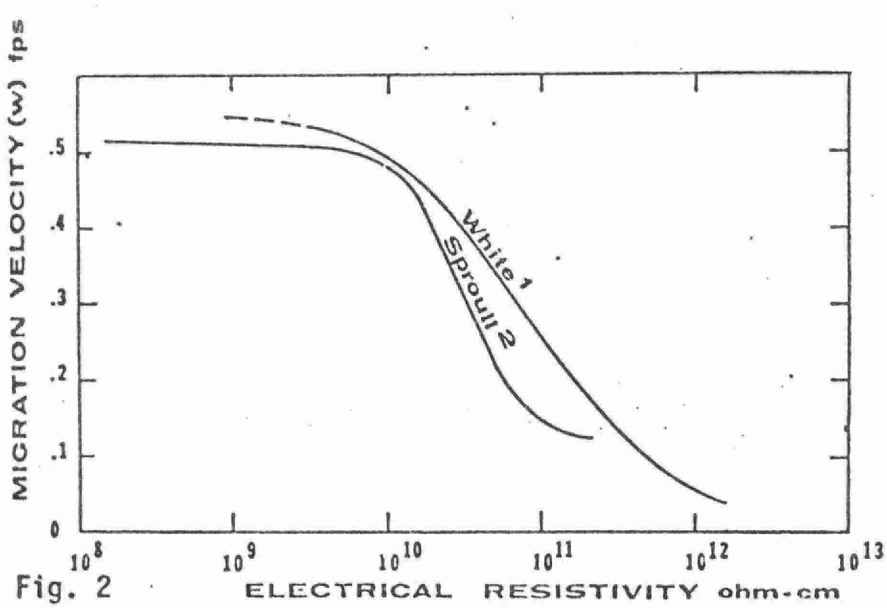

MIGRATION VELOCITY (w) fps
.5
.4
.3
.2
.1
0
White 1
Sproull 2
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
ELECTRICAL RESISTIVITY ohm-cm

Fig. 2

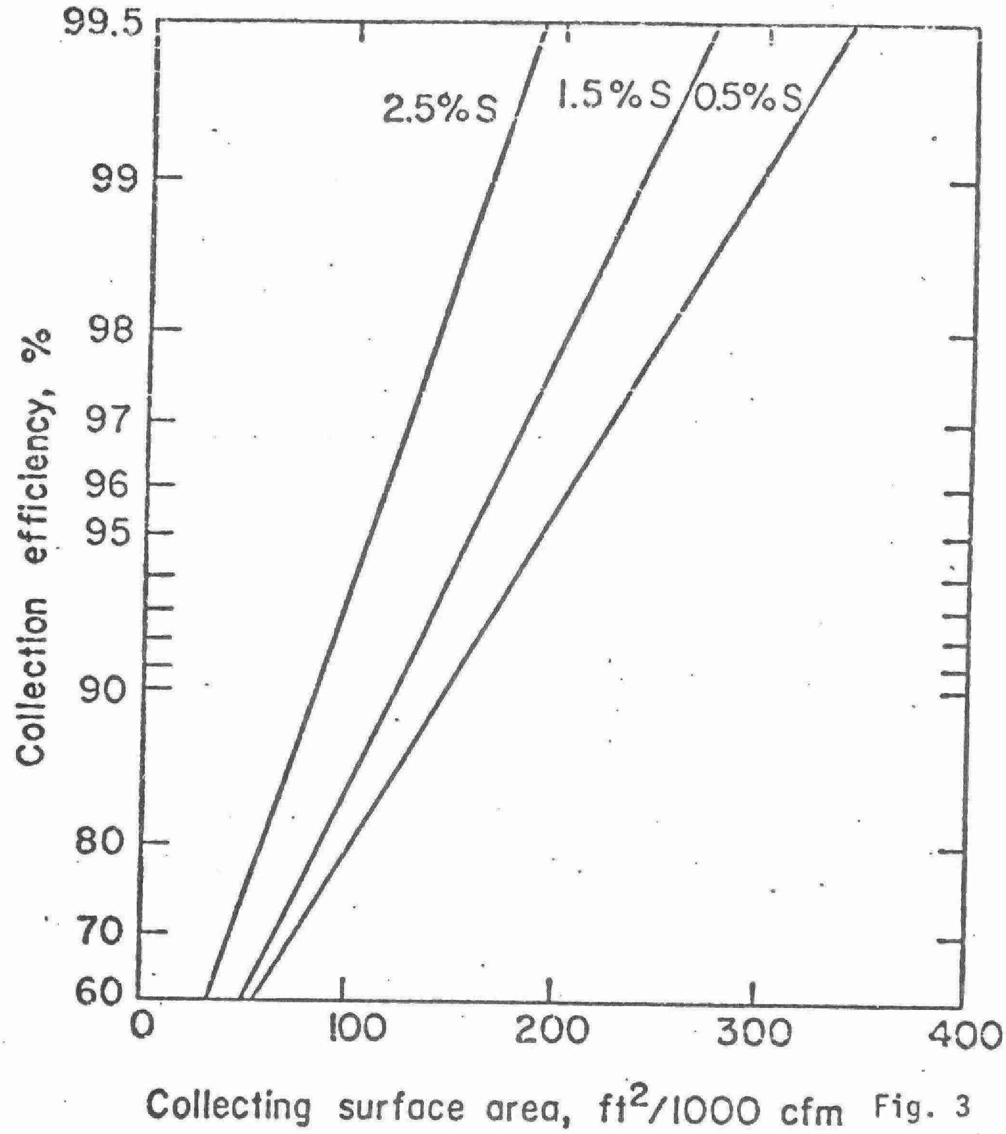

99.5
99
98
97
96
95
90
80
70
60
2.5% S
1.5% S
0.5% S
0
100
200
300
400
Collection efficiency, %
Collecting surface area, ft²/1000 cfm

Fig. 3

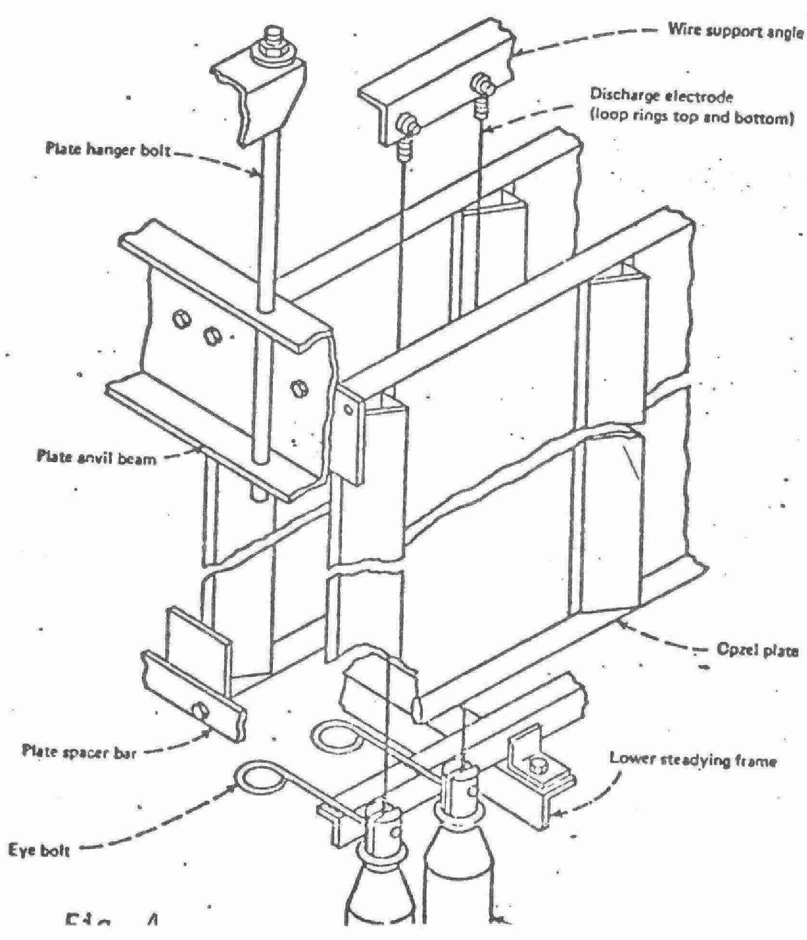

Wire support angle
Discharge electrode
(loop rings top and bottom)
Plate hanger bolt
Plate anvil beam
Opzel plate
Lower steadying frame
Plate spacer bar
Eye bolt

Fig. 4

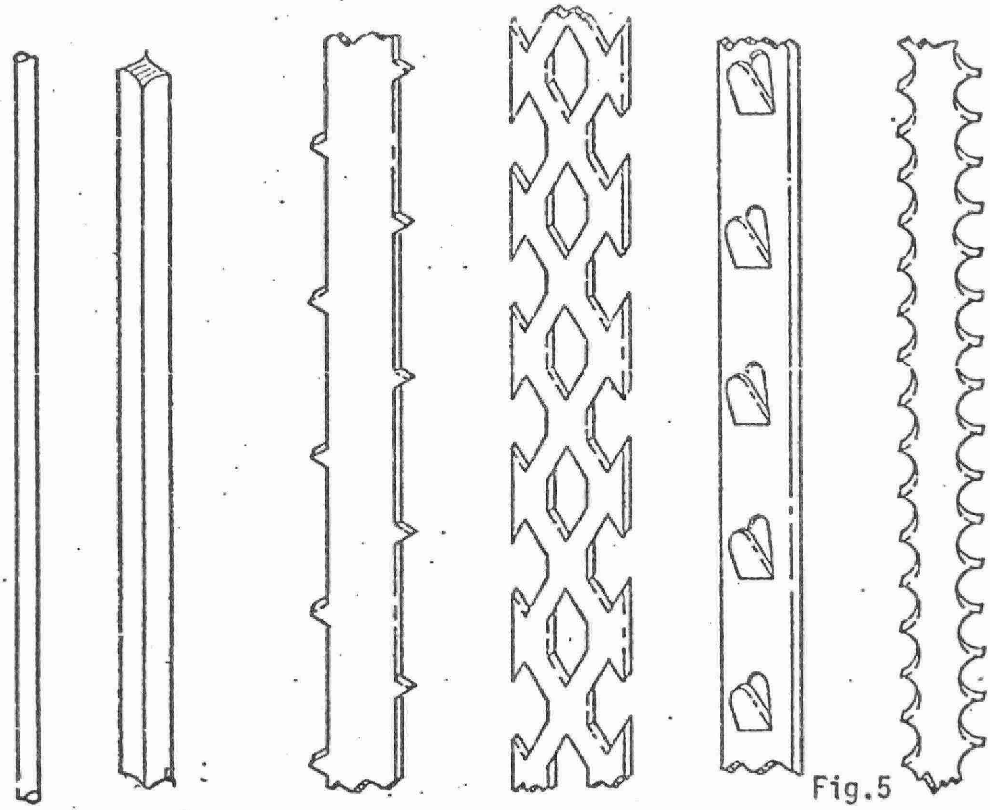


Fig.5

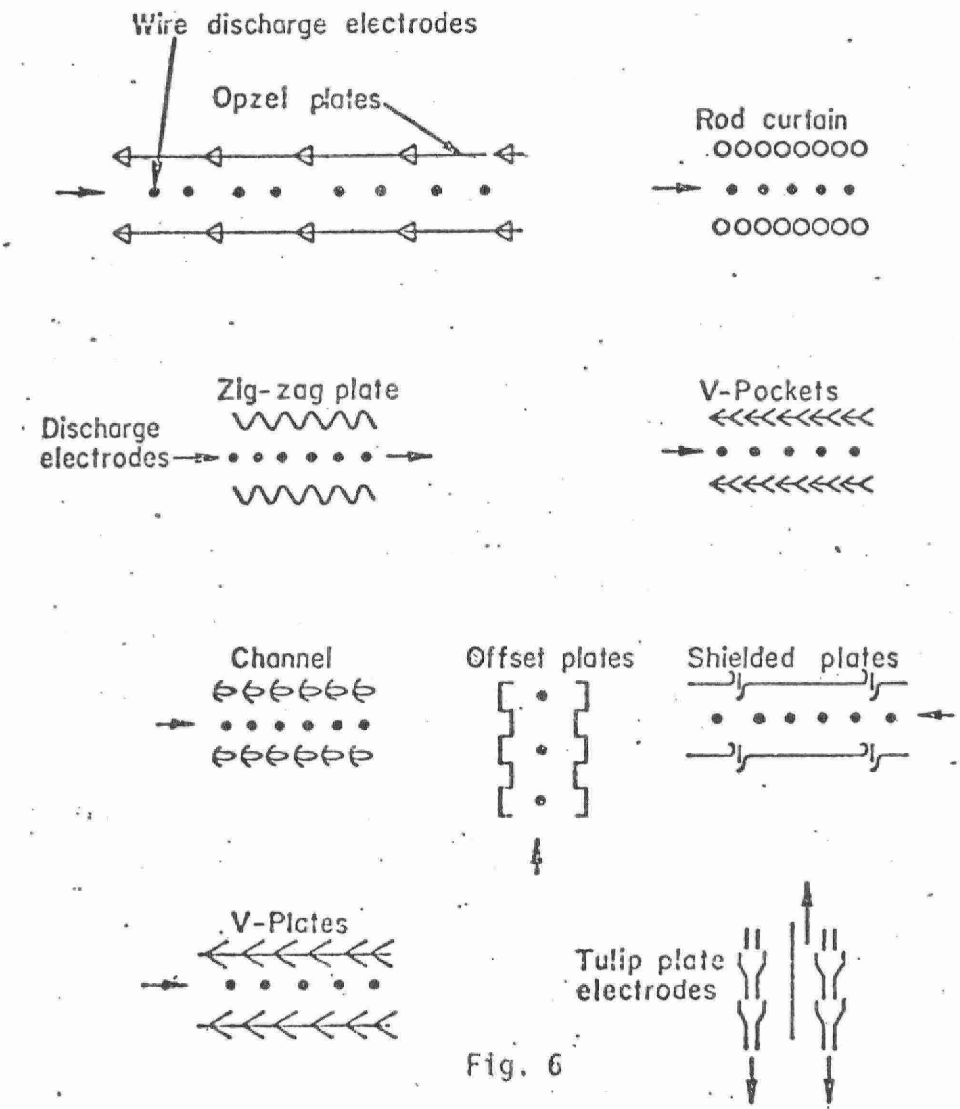

Wire discharge electrodes
Opzel plates
Rod curtain
Zig-zag plate
Discharge electrodes
V-Pockets
Channel
Offset plates
Shielded plates
V-Plates
Tulip plate electrodes

Fig. 6

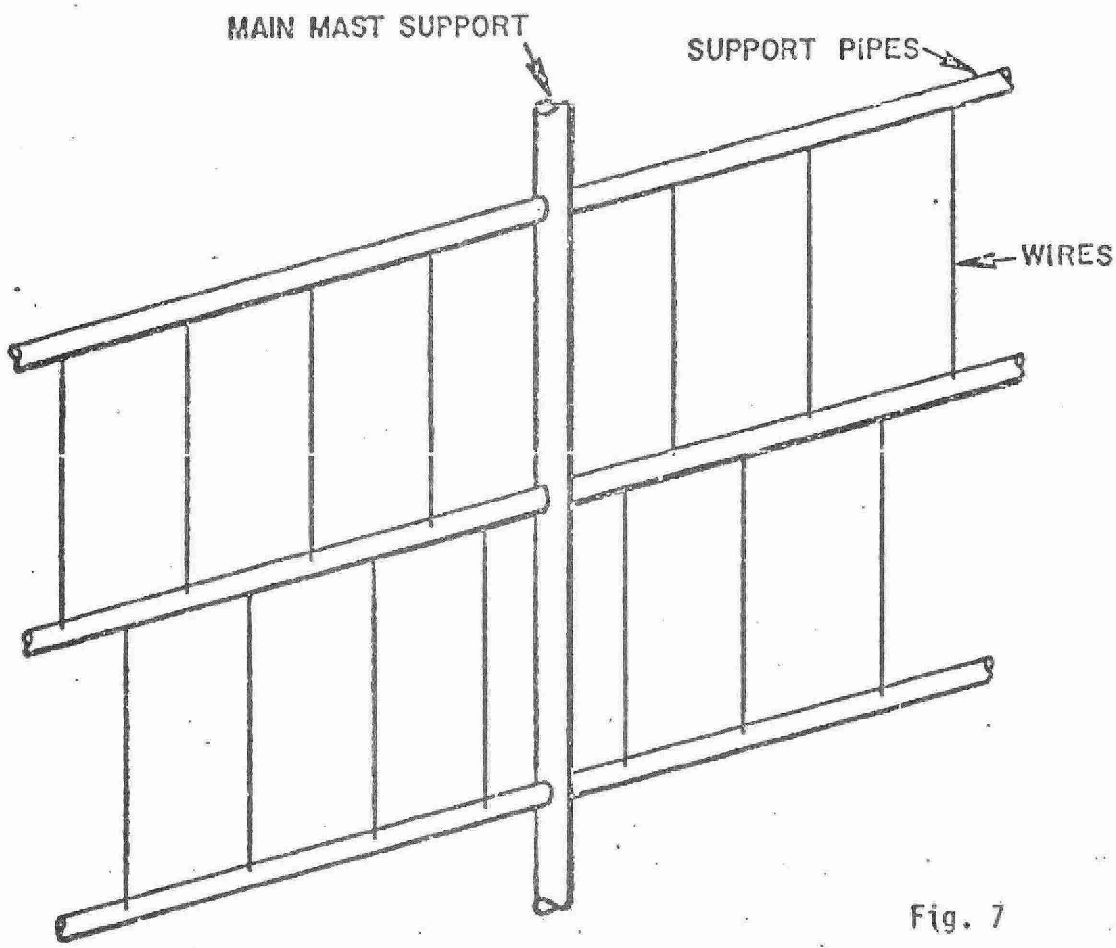

MAIN MAST SUPPORT
SUPPORT PIPES
WIRES

Fig. 7

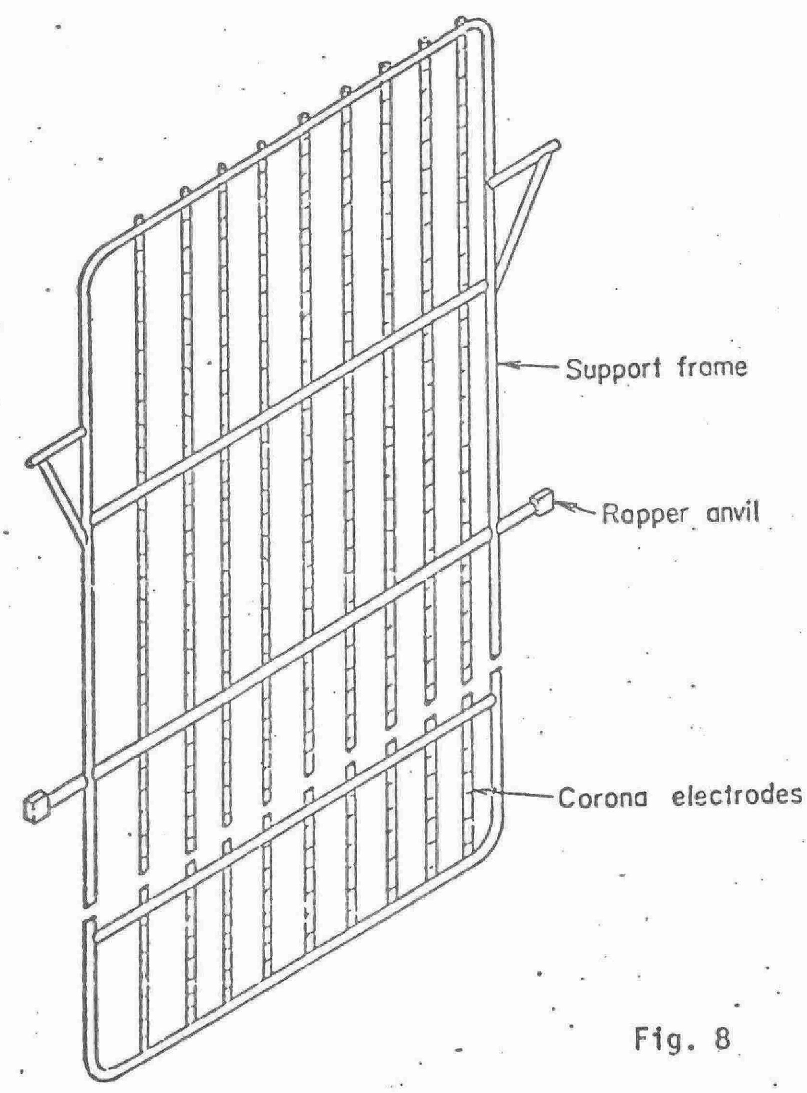

Support frame
Rapper anvil
Corona electrodes

Fig. 8

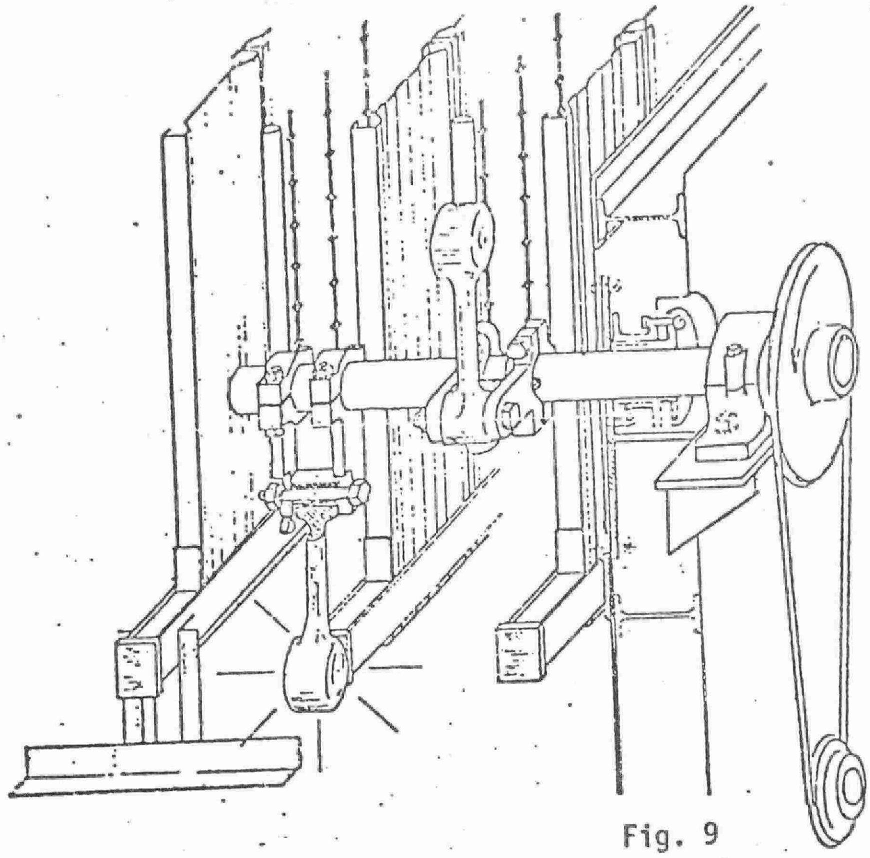


Fig. 9

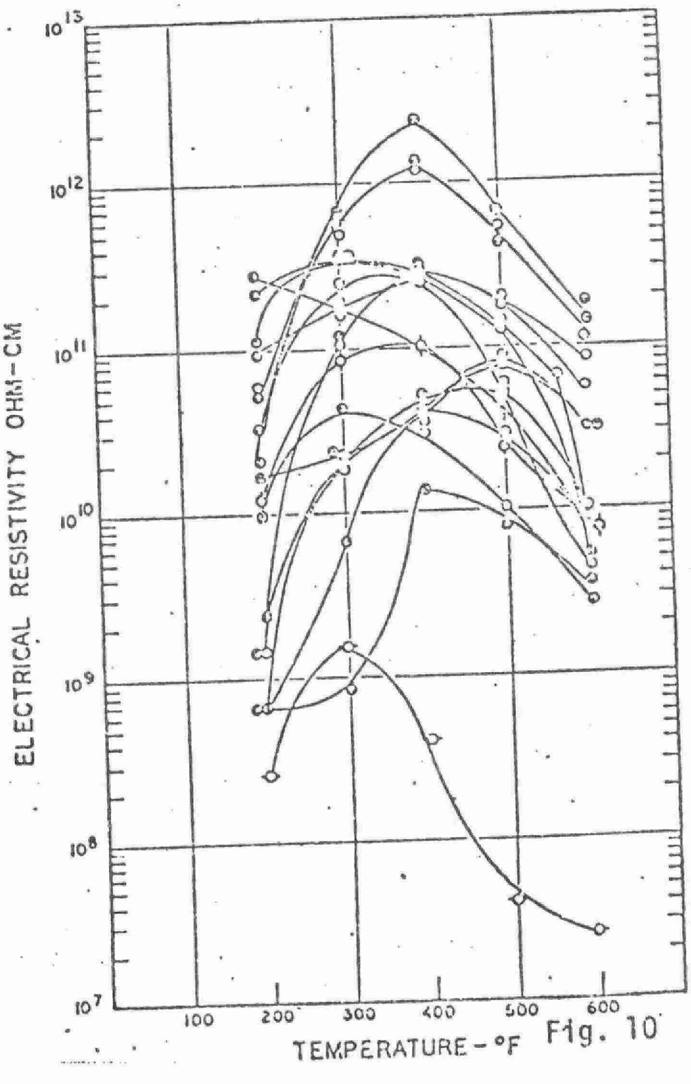

ELECTRICAL RESISTIVITY OHM-CM
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
100
200
300
400
500
600
TEMPERATURE - °F

Fig. 10

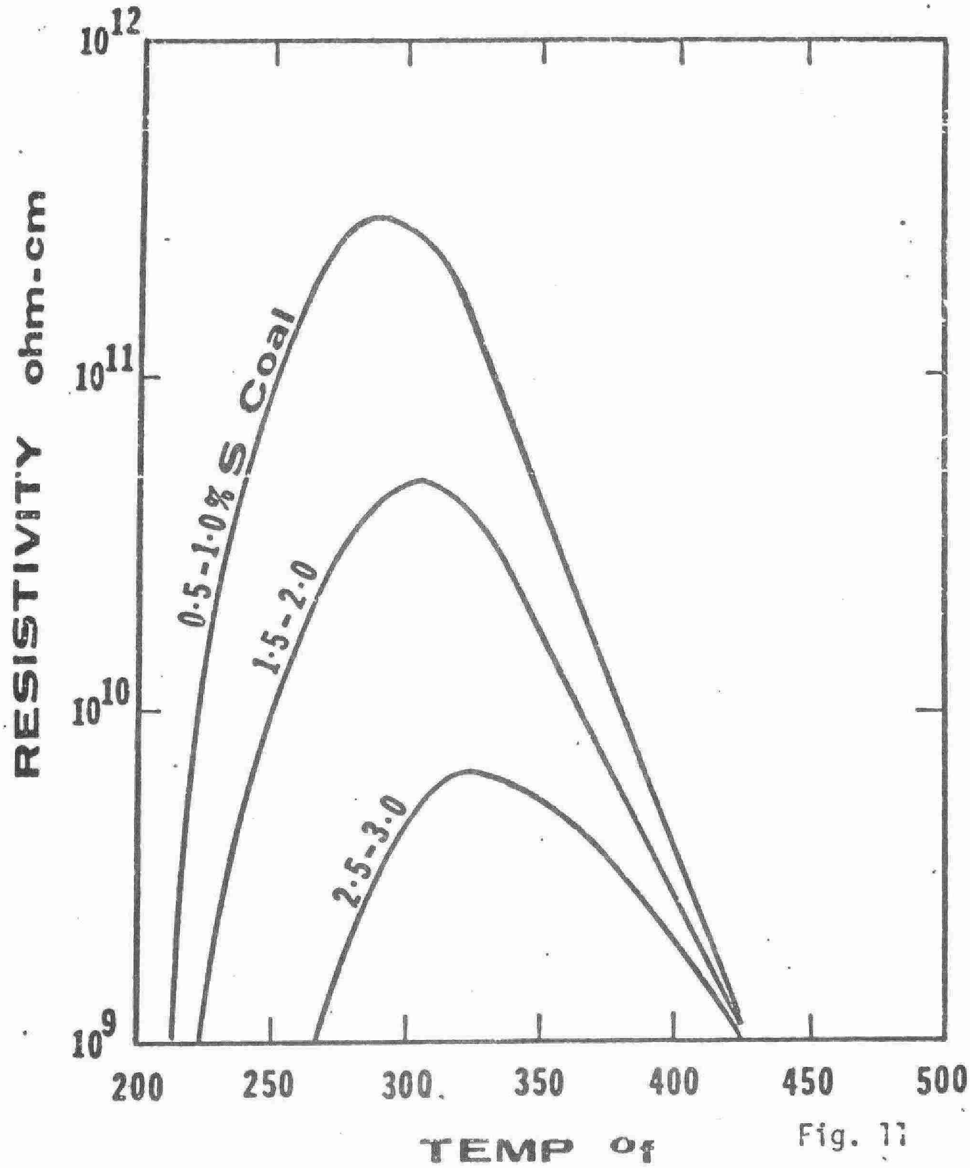


Fig. 11

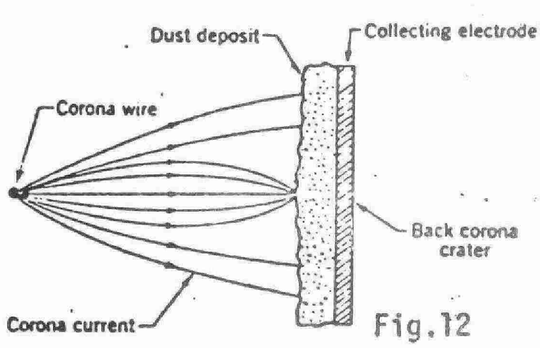


Fig.12

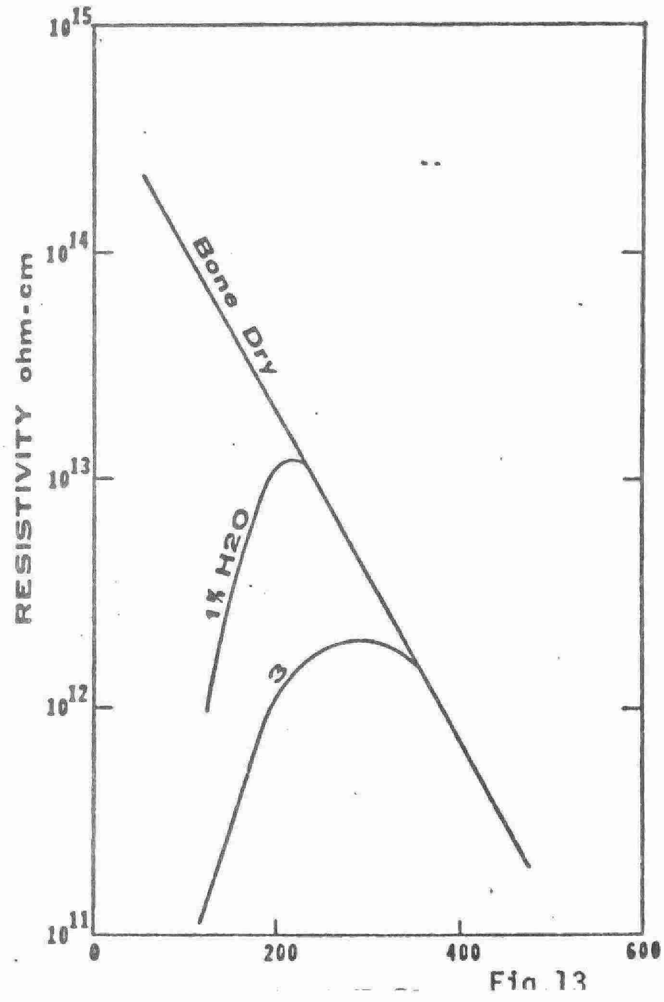


Fig.13

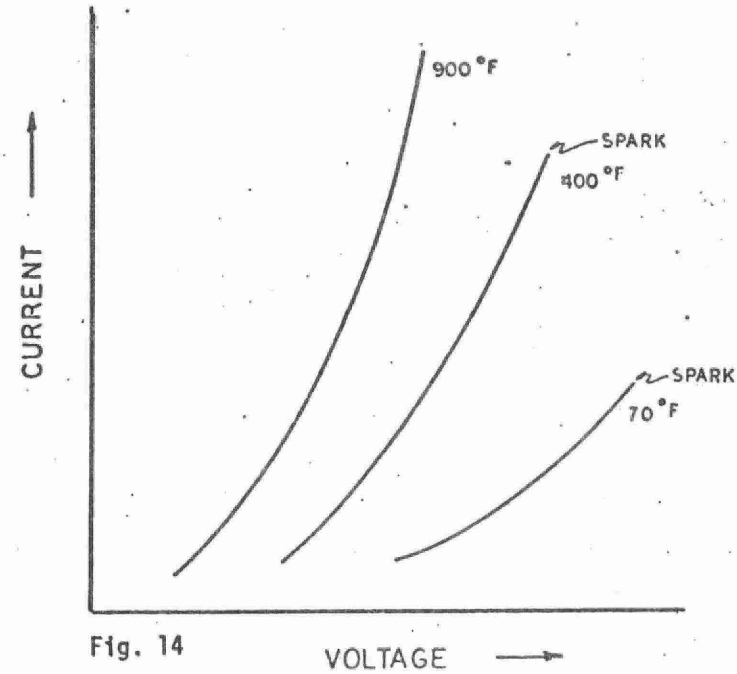


Fig. 14

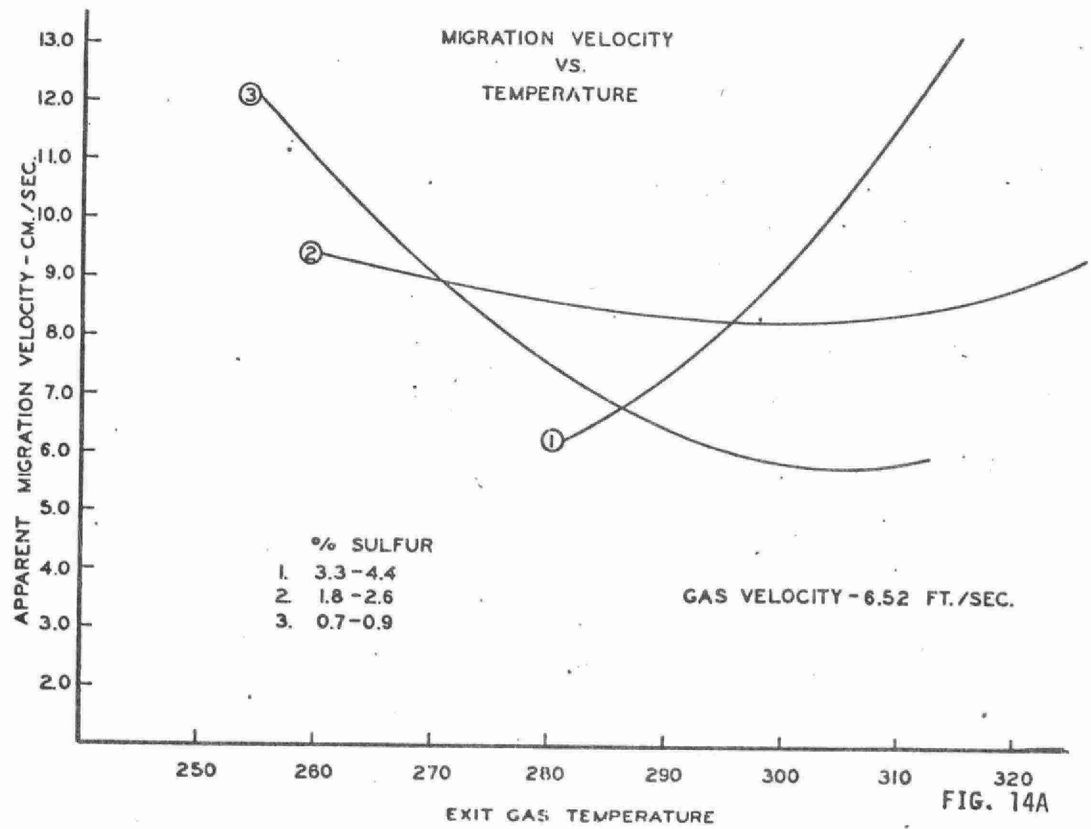


FIG. 14A

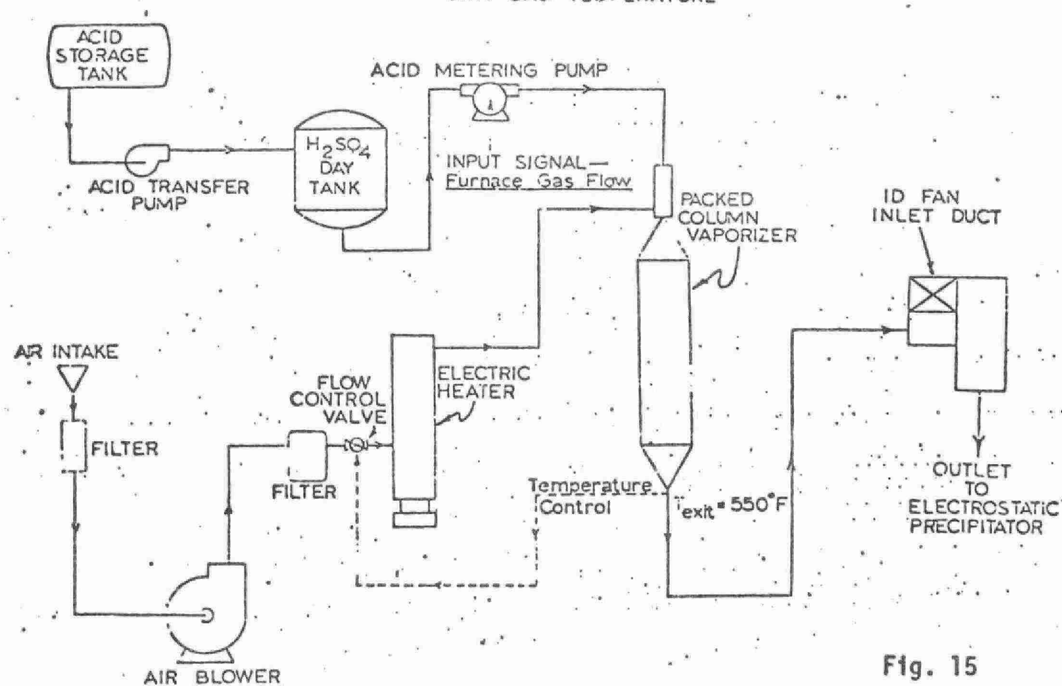


Fig. 15

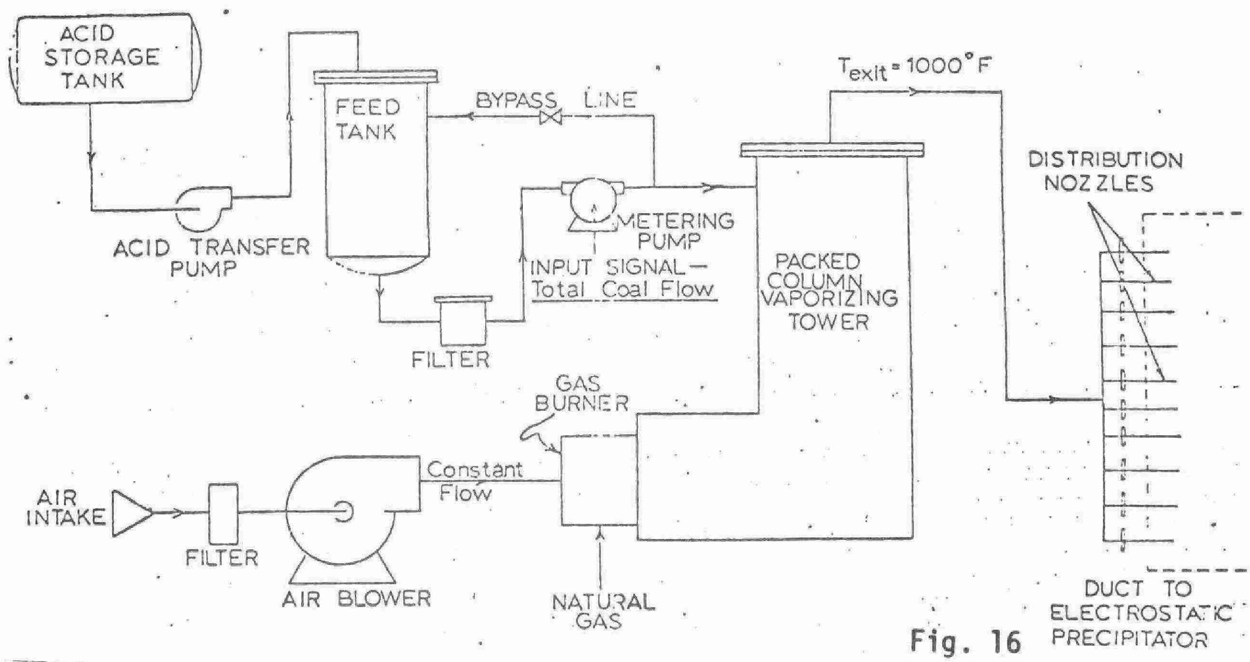

ACID STORAGE TANK
FEED TANK
BYPASS LINE
ACID TRANSFER PUMP
METERING PUMP
INPUT SIGNAL— Total Coal Flow
FILTER
T_{exit} = 1000°F
PACKED COLUMN VAPORIZING TOWER
DISTRIBUTION NOZZLES
GAS BURNER
AIR INTAKE
FILTER
Constant Flow
AIR BLOWER
NATURAL GAS
DUCT TO ELECTROSTATIC PRECIPITATOR

Fig. 16

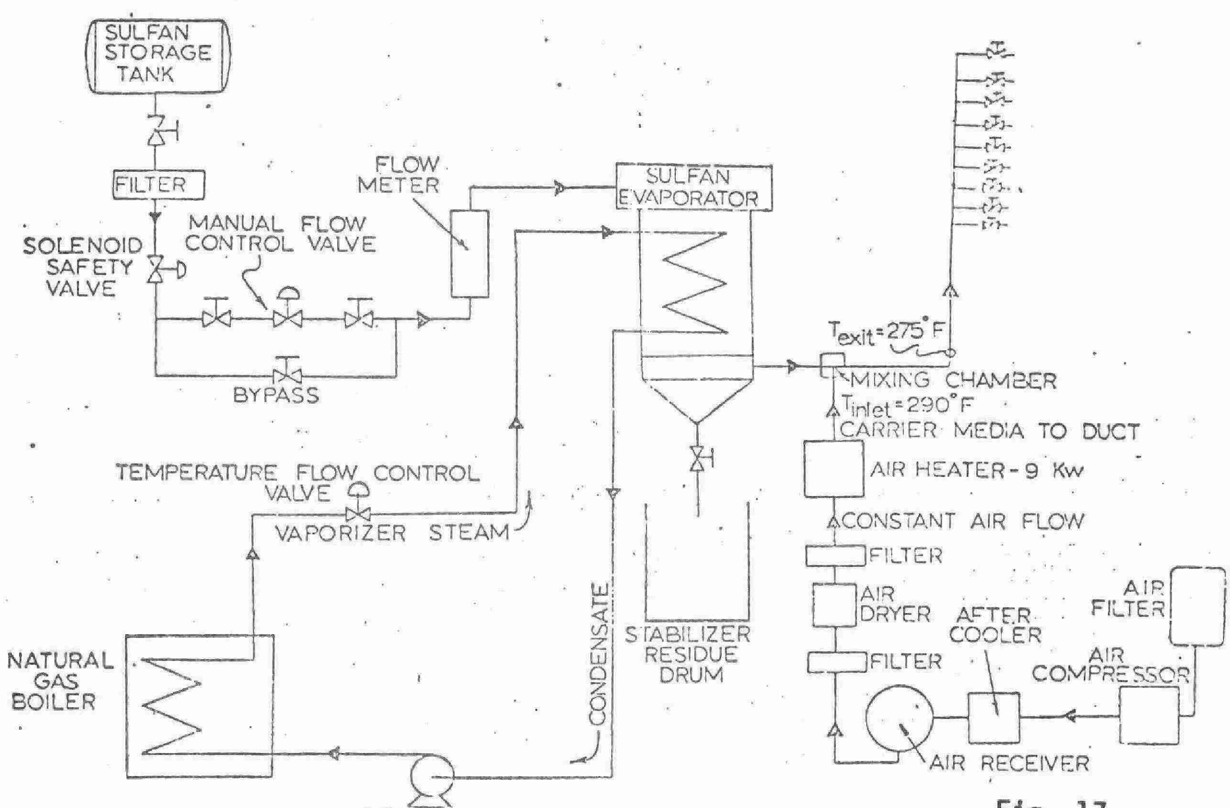

SULFAN STORAGE TANK
FILTER
SOLENOID SAFETY VALVE
MANUAL FLOW CONTROL VALVE
FLOW METER
SULFAN EVAPORATOR
BYPASS
TEMPERATURE FLOW CONTROL VALVE
VAPORIZER STEAM
NATURAL GAS BOILER
FEED PUMP
CONDENSATE
STABILIZER RESIDUE DRUM
T_{exit}=275°F
MIXING CHAMBER
T_{inlet}=290°F
CARRIER MEDIA TO DUCT
AIR HEATER - 9 Kw
CONSTANT AIR FLOW
FILTER
AIR DRYER
AFTER COOLER
AIR FILTER
FILTER
AIR COMPRESSOR
AIR RECEIVER

Fig. 17

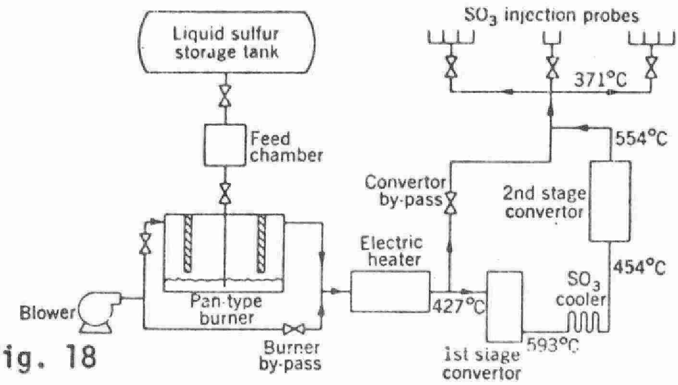


Fig. 18

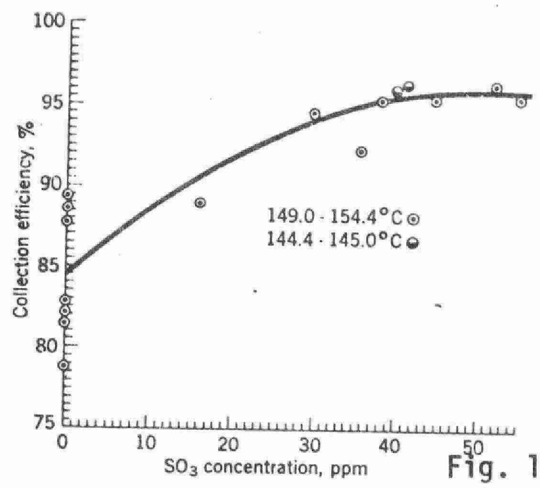


Fig. 19

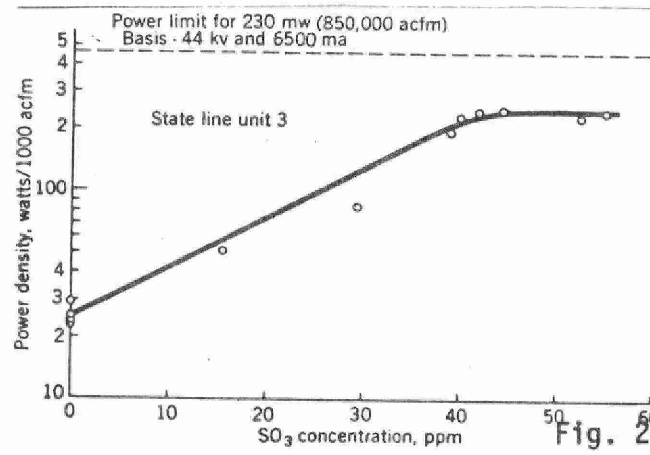


Fig. 20

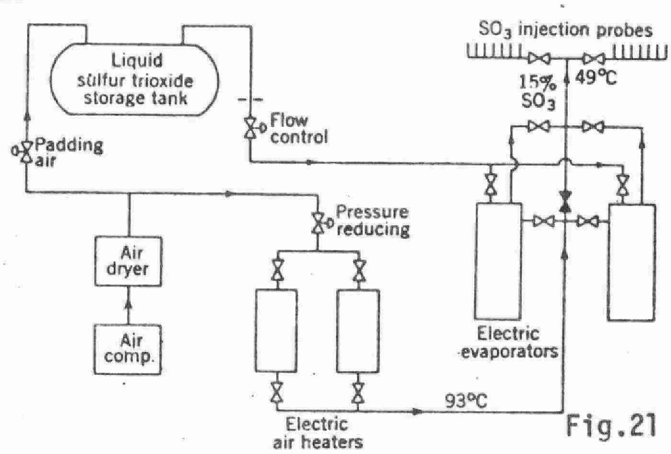


Fig.21

36. Record of a Visit to Public Service of Colorado, Cherokee GS

Mr. R.W. Smith, of CTS, Mr. F.G. Reeves, of Generation - Mechanical, and I visited the head offices of Public Service of Colorado and their Cherokee Plant, and discussed the subject of flue gas conditioning with Mr. Green, Mr. Sutton and Mr. Blatnick, on September 26, 1974.

Mr. Green presented us with a copy of a paper on the subject, which he had recently written (a copy is attached). It is apparent from Table No. 3 in this paper that flue gas conditioning can not be thought of as a cure for all precipitator ills. This paper also adequately covers the company's experience with precipitators and flue gas conditioning, though it should perhaps be stated that Lodge Cottrell supplied the liquid SO_3 (sulphan) conditioning equipment, Joy Manufacturing the sulphuric acid conditioning equipment on Cherokee unit No. 3 and UOP, the sulphuric acid conditioning equipment on the Arapahoe and Cameo units.

Mr. Green believes that, in the case of a new unit, where a choice is available, there is no question that a hot precipitator is the best solution to high resistivity ash collection problems. Their experience has been that gas conditioning is a high maintenance item which, in the case of a Lodge Cottrell system at least, is also costly, because of the high cost of the Sulphan. Because they rely on these systems to meet environmental regulations, it is apparent that they should be very reliable, if they are to be satisfactory. They state that the UOP system at the Araphoe plant is the most reliable of the systems that they have installed.

It is also a fact that SO_3 is an extremely dangerous fluid to have in storage. They related the case of a local plant which lost 55 gallons of liquid SO_3. This resulted in the evacuation of a very large number of people. Fifteen tons of liquid SO_3 is stored in one tank at the Cherokee plant, and this is a source of concern for them.

They believe that the SO_3 should have a residence time in the flue of at least 5 seconds, before entering the precipitator. The reason for this is not that the chemical reaction needs that long, but this residence time is required for satisfactory mixing. I personally wonder how many units there are in which it is possible to inject the SO_3 200-250 feet upstream of the precipitator. Furthermore, I wonder if a better approach isn't to ensure that good mixing and distribution is achieved at the point of injection, because poor initial distribution may result in over-conditioning of some portions of the ash, with other portions having no conditioning at all.

It is perhaps significant that, in all but one unit at the Cherokee Plant, UOP particulate scrubbers have been added, to meet state and federal air quality regulations. The unit which has not been back-fitted with a scrubber is unit 2 at Cherokee.

Again we were unfortunate, at the time of our visit to the plant, that gas was being burned on all units except for No. 4. Here, I understand that the first of the four sections of the scrubber was being commissioned and the unit was being operated without the precipitator. The plume understandably enough, was very dirty.

I understand from Mr. Green that Public Service of Colorado used Southern Research Institute and Denver Research Institute (Mr. T. Nevin), to measure in situ fly ash resistivities. Mr. Green expressed confidence in the capabilities of either of these organizations to do that type of work.

It is apparent from Table 3 of Mr. Green's paper, that flue gas conditioning did not, in many instances achieve the level of collection efficiencies that we would consider to be necessary at our installations. The visit to the Cherokee Plant, however, revealed that many of the precipitators would have been considered undersized even for higher sulphur Eastern US coal. As stated previously in this report, I don't believe that gas conditioning can be viewed as a cure-all, but I do believe that, where a precipitator is performing satisfactorily on a fly ash with 'normal' resistivity, flue gas conditioning will permit that precipitator to perform at almost the same level of efficiency with high resistivity fly ashes produced from low sulphur coal.

C.W. Dawson
Equipment Studies Engineer - Specialist
Generation Concept Department

cc J.W. James
R.E. Waters
F.G. Reeves
R.W. Smith

37. Record of a Visit to Colorado Springs, Martin Drake Generating Station

Mr. R.W. Smith of CTS, Mr. F.G. Reeves of Generation Mechanical and I visited the above plant on the 25th of this month. The purpose of the visit was to discuss the subject of flue gas conditioning.

The Martin Drake plant has a total of seven units, the first four being very small and used only for standby duty. The other three units are relatively recent and have much larger outputs, unit #5 having a nominal output of 44MW, unit #6 a nominal output of 60MW and unit #7, commissioned earlier this year, has a nominal capacity of 127MW. This larger and newer unit has been fitted with a hot side precipitator, but units 5 and 6 are fitted with flue gas conditioning equipment as a means of improving the precipitator collection efficiency when burning the low sulphur (less than 0.8%, as received) Northern Colorado coal burned at the plant. Unit 5 is fitted with a Wahlco gas conditioning unit which catalytically converts SO_2 gas to SO_3 gas, which is then injected into the flue gas, just downstream of the air preheater, at concentrations of 20 to 30 ppm. Results from this unit are claimed to be good, with the plume from the stack only visible at maximum loads. Jim Lawrence claims that the Wahlco unit has given little trouble from an operational and reliability standpoint, though it should be noted that the unit has only operated for about two weeks, so far.

Unit #6 is fitted with a UOP gas conditioning unit, which evaporates sulphuric acid to form SO_3, which is then injected into the flue gas at concentrations of 15 to 20 ppm. Injection to the flue gas stream is via three 8 in lines, which enter the duct in the enlargement zone immediately upstream of the precipitator. Jim Lawrence claims that performance on this unit is not as good as that achieved on unit 5. He attributes this to several factors, all of which influence the SO_3 gas distribution. These factors are:

(1) The short resident time available for the SO_3 to condition the fly ash, this being only the few feet of divergent duct upstream of the precipitator.

(2) The poor SO_3 gas distribution achieved by the three 8 in lances into the duct.

(3) The poor velocity distribution which exists in the flue gas duct upstream of the precipitator.

However, he claims that ash conditioning has improved the appearance of the plume from unit 6. Mr. Lawrence also indicated that operating and maintenance problems were more numerous with the UOP system.

In a comparison of the two systems, the following points can be made.

(1) The Wahlco system is more compact than the UOP system, utilizing less compressor and electric heater capacity.

(2) The Wahlco system is apparently easy to operate and more reliable than the UOP system, though this observation is only based on two weeks experience of the Wahlco system.

(3) The Wahlco system generates SO_3 gas at about 600^{o}F, whereas the UOP system generates SO_3 gas at about 400^{o}F. Because of the lower temperature, the piping downstream of the evaporator has to be glass lined, to prevent corrosion in the UOP system. This tends to make the piping downstream of the evaporator difficult to work with. All SO_3 piping, in both systems, is, of course, heavily lagged.

(4) The Wahlco system uses seven, 2 in diameter lances, evenly spaced across the duct and just downstream of the air preheater. The UOP system, uses only three 8 in lances, positioned only a few feet upstream of the precipitator. Also, the location of the lances did not appear to be ideal, two being close together half way up the duct with the third near the bottom. However, it should be noted that there was very little opportunity to install the lances much further upstream, of the unit serviced by the UOP system. Also, it has already been noted that the velocity distribution in the duct work upstream from the precipitator was a long way from ideal.

(5) Sulphuric acid is probably a less convenient fluid to work with than SO_2. It is corrosive and protective suits have to be worn when working with it. SO_2 on the other hand is much less corrosive, has a very noticeable smell, making it safe to work with, and leaks can be detected easily with the aid of ammonia. However, SO_2 is apparently difficult to obtain and does leak rather easily. This utility had to go as far afield as British Columbia to obtain a supply of SO_2. Both the sulphuric acid and the SO_2 require a storage tank of much the same size.

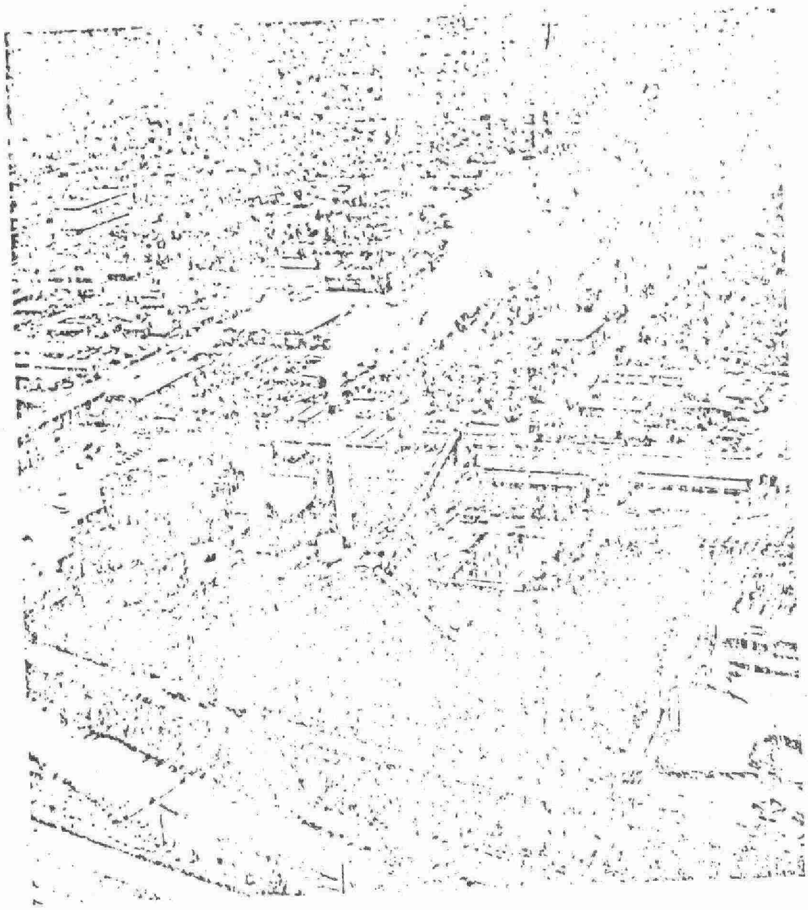
Unfortunately, while we were at the generating station, all the units were burning gas, so that it was not possible to evaluate the cleanliness and opacity of the plumes for ourselves. However, we were able to obtain some descriptive literature containing a photograph which shows unit #6 firing coal with gas conditioning in operation. It can be seen that the plume remains clearly visible. It is, I believe, intended to enlarge the precipitator and modify the gas flows to correct the problem on this unit. The photograph was taken before unit 5 had the flue gas treatment installed, and the unit was burning gas when the photograph was taken.

Colorado Springs Public Utilities seem to have very scanty knowledge of their coal and ash properties. An example of the only analysis that they have are attached to this report. Furthermore, they did not measure fly ash resistivity before committing themselves to flue gas conditioning equipment. This would seem to me to be a very hit-and-miss way of committing oneself to what must be quite a large expenditure. It was also interesting to note that many of the remarks made at the conference on hot side precipitators about expansion problems were born out on the American Standard precipitator installed on unit #7. Here extensive work was being performed to strengthen the supporting structure and also I believe to repair cracks which has already developed. It is interesting to note that so far this unit has only operated with one pulverizer burning coal. All remaining generation has been with natural gas. A clear stack was obtained when the unit was burning coal.

Prepared by: C.W. Dawson
Equipment Studies
Engineer Specialist
Generation Concept Department

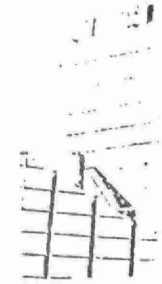
CWD/ch

cc Mr. J.W. James
Mr. R.E. Waters
Mr. F.G. Reeves
Mr. R.W. Smith



Martin Drake Power Plant
Serving the People of the
Colorado Springs region

The Drake Plant plays a vital role in providing reliable electric service to the Colorado Springs Area. This 127,000 KW addition marks the final electric generation facility possible at this site. Additional power needs will be supplied from the new site about 3 miles south of the City of Fountain, Colorado.



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ash (pa
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ash stor
used as

EDNA MINE

City of Colorado Springs

tsburg & Midway
Analyses By

August - 1974
Month - Year

Date	Lab No.	Weight Tons	As Received Moist.	As Received Ash	As Received Sul.	As Received BTU	Dry Ash	Dry Sul.	Dry BTU	MAF BTU	Premium (Penalty) Ton	Premium (Penalty) Total
-1	155	1,551.55	10.69	10.45	.74	10,807	11.71	.83	12,101	13,706		
-6	155A	1,565.65	11.49	11.42	.72	10,515	12.90	.81	11,880	13,639		
-7	156	1,571.70	10.37	8.98	.68	10,885	10.02	.76	12,144	13,496		
-13	157	1,548.85	10.75	8.34	.76	10,971	9.35	.85	12,292	13,560		
-14	158	1,542.50	11.32	9.80	.72	10,895	9.56	.79	12,285	13,584		
-17	158A	1,550.50	10.62	9.80	.72	10,811	10.96	.81	12,096	13,585		
-27	159	1,539.55	10.15	10.22	.74	10,869	11.38	.82	12,096	13,649		
-28	160	1,504.20	10.61	10.37	.74	10,811	11.60	.83	12,094	13,681		
-29	161	1,514.80	10.47	10.27	.69	10,747	11.47	.77	12,004	13,559		
-30	162	1,516.60	10.76	10.27	.68	10,682	11.51	.76	11,970	13,527		
TOTAL		15,405.90										
AVERAGE			10.73	9.86	.71	10,799	11.05	.80	12,096	13,599		

HAZEN RESEARCH, INC.

4601 INDIANA STREET
GOLDEN, COLORADO • 80401
TELEPHONE 303/279-4501

Mr. B. G. Godec
Department of Public Utilities
P.O. Box 1103
Colorado Springs, Colorado 80947

Date: September 17, 1974

Sample Received:	Sept. 9, 1974
HRI Project No.	1091
HRI Series No.	7356-1
Purchase Order	10228 UG

Sample Designation	74-36	
	As Received	Dry Basis
Moisture (%)	10.73	
Ash (%)	15.71	17.60
Volatile Matter (%)		
Fixed Carbon (%)		
Calorific Value (Btu/lb)	9,762	10,936
Sulfur (%)	0.84	0.94
Mineral Matter Free (Btu/lb)		13,530
Initial Deformation °F		
Softening °F		
Hemispherical °F		
Fluid °F		

By: John C. Jarvis
John C. Jarvis
Manager, Analytical Laboratory

ljb

For coal received September 3, 4, 5, 6, 1974
697.34 Tons - 25 Loads